INFLUENCE OF OPERATOR SIZE ON REGULATORY COMPLIANCE IN THE UNCONVENTIONAL OIL & GAS INDUSTRY

by

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Executive Summary:

The hydraulic fracking boom of the last two decades has led to a dramatic increase in the number of wells drilled across the United States as well as a drastic increase in the number of operators working in the industry. Within these new companies entering the industry, there is substantial diversity among operator type and size. While there are still a few large players in the industry, the fracking boom has rapidly expanded the number of small and independent operators. While a benefit for small entrepreneurship in the United States, there is some question within the industry as to whether or not small oil and gas operators are as safe as large operators. This study explored this idea and tested a general industry assumption that smaller firms are more likely to commit or be assessed regulatory (administrative and environmental) violations at the state level.

To test whether or not small oil and gas operators are more or less likely to commit violations at the well site than larger companies, a data analysis of oil and gas inspection and violation data was conducted in two states that have been active in the unconventional oil and gas industry over the last 2 decades. The two states selected for this study were Pennsylvania and Colorado. Violation and inspection data was analyzed from 2005 to 2014 to see if operator size had an impact on the number of violations assessed/committed per inspection. To accompany this analysis, informational interviews were conducted with relevant stakeholders and industry experts in and around the oil and gas industry. These interviews were conducted to gain an understanding of general industry assumptions in the oil and gas sector related to size and compliance and to glean information that could not be ascertained from the analyzed datasets alone. These interviews were then analyzed and compared to the hard data collected from Pennsylvania and Colorado.

The results of this study concluded that there is a general industry wide assumption that small operators in the oil and gas industry are more likely to commit/be assessed state compliance violations than larger firms. The data from Pennsylvania and Colorado appear to confirm this assumption. The negative binomial regression models run in this study indicate that in both Pennsylvania and Colorado, smaller firms commit more violations per inspection than medium or large sized firms. While some uncertainty surrounds the accuracy of the datasets used in the study, the results suggest that larger companies commit fewer violations than smaller firms. A rationale for this conclusion may be that larger firms have better technology, more employees, greater redundant expertise, and more to lose than smaller firms.

These results have broad implications for both state regulators and the wider industry. From a regulatory perspective, if state regulators wish to promote environmental safety at all costs, then they may want to increase barriers to entry or regulatory oversight of smaller firms knowing that small firms are more likely to commit violations than larger firms. From an industry perspective, these results may indicate that larger firms should promote a more cooperative environment with smaller firms. If small firms are more likely to be bad actors than larger firms, then it may be possible that a few small firms are hurting the image of the industry as a whole, and as a result the larger, more compliant companies. By sharing information and helping smaller firms comply with regulations, large operators may be able to help their own operations by improving compliance among smaller firms.

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List of Abbreviations:

Fracking	Hydraulic Fracturing
OR	Operator of Record
DEP	Pennsylvania Department of Environmental Protection
COGCC	Colorado Oil and Gas Conservation Commission
ENV	Representative of an Environmental Group
REG	Representative of a state Regulatory Body
SMALL	Oil and Gas Operator Representing a small oil and gas producer
LARGE	Oil and Gas operator representing a large oil and gas producer
EMS	Environmental Management System
BACT	Best Available Control Technology
API	American Petroleum Institute
O&G	Oil and Gas

Section I

Introduction:

The expansion and discovery of US onshore natural gas and oil reserves over the last 20 years has dramatically altered the American energy supply outlook. With the investment in and expansion of shale gas extraction technologies, vast unexplored oil and gas resources are beginning to be exploited across the country. Expansion into previously unutilized shale plays is most heavily linked to the development of economical and efficient well enhancement and hydraulic fracturing techniques.

Hydraulic fracturing, known colloquially as fracking, uses pressurized water, chemical additives, and a variety of other materials such as sand to crack deep lying shale bed formations creating fissures that allow oil and natural gas to escape from formations and flow to the surface via horizontal and vertical wells.[1] To access this resource, deep wells are drilled into horizontal shale deposits from the surface. To increase well integrity and prevent spills and potential contamination, the wellbore is lined with steel and cased in cement throughout the drilling process.[2] Once the well has reached the producing layer, the well is perforated and vast amounts of water and fracking fluid are pumped down the well to 'fracture' the formation. The released oil and gas from the formation then flow back up the well and are collected at the wellhead and are separated from the backflow water known as 'produced water'.[3]

[1] Appendix 1
[2] Appendix 2
[3] American Petroleum Institute. Policy Issues. Hydraulic Fracturing: Safe Oil and Natural Gas Extraction. Accessed February 2015. http://www.api.org/policy-and-issues/policy-items/hf/hydraulic-fracturing-safe-oil-natural-gas-extraction

While hydraulic fracturing is not a new drilling technique[4], and has in fact had been used over a million times prior to 2002[5], improvements in drilling technology and chemical additives have made the technique more profitable and accessible over the last 15 years. As this technology has become more available, it along with elevated oil and gas prices, have helped drive an oil and natural gas boom across the United States.

In 2000, natural gas from shale accounted for only about 1% of the total natural gas production in the United States; however, by 2010, shale gas accounted for 23% of all natural gas produced in the country.[6] In the years to come, that percentage is expected to rise dramatically as the technique becomes more commonplace in the industry.[7] By 2012, 95% of all new oil and gas wells in the country were hydraulically fractured, accounting for more than 43% of total US oil production and 67% of natural gas production.[8] Hydraulic fracturing is ubiquitous in 32 states across the country and is under consideration in a number of others. Nearly every state in the country holds some form of oil and gas play[9] (i.e. shale gas, tight gas, coal bed natural gas…etc.) and will be impacted by the process to some degree.

While the development of American shale gas has obvious economic benefits, as well as the environmental benefit of the displacement of more carbon intensive fuel sources that have

[4] Hydraulic fracturing was first used in 1947 in a well in Grant County, Kansas. Source: "Prudent Development – Realizing the Potential of North America's Abundant Natural Gas and Oil Resources" National Petroleum Council, 2011. p.169. http://npc.org/
[5] "Prudent Development – Realizing the Potential of North America's Abundant Natural Gas and Oil Resources" National Petroleum Council, 2011. p.169. http://npc.org/
[6] Heikkila T, Pierce J, Gallaher S, Kagan J, Crow D, Weible C. 2013. Understanding a Period of Policy Change: The Case of Hydraulic Fracturing Disclosure Policy in Colorado. Review of Policy Research.
[7] *Id.*
[8] IHS Global Insights, "Measuring the Economic and Energy Impacts of Proposals to Regulate Hydraulic Fracturing, 2009; and Energy Information Administration, "Natural Gas and Crude Oil Production," December 2010 and July 2011.
[9] Appendix 3-6.

much higher emissions rates (such as coal) in the electricity sector[10], unconventional oil and gas development is not without risk. Due to the complexity of the drilling and production process, there are a number of opportunities for the technique to produce environmental and occupational harm.

The oil and gas industry, as well as state regulators, are concerned with a variety of environmental challenges associated with unconventional development. Some of these challenges include: water, air, and waste. While there is no evidence to date that fracking fluid has or can percolate from the producing zone of a shale formation up into ground or surface waters from a properly drilled well[11], there is evidence that surface spills and poor well construction can place ground and surface water supplies at risk.[12,13] Fugitive methane emissions from the wellhead as well as emissions from drilling equipment provide air quality concerns[14] and management and disposal of produced water and drilling mud provide challenges for waste treatment and disposal.[15] These environmental risks have led to the regulation of fracking and the unconventional oil and gas industry across the US and have created strong opposition against the practice by public interest groups and some within the environmental community.

The unconventional oil and gas industry is currently regulated at the state level. At the moment, no comprehensive federal regulations are in place to monitor and control the fracking industry; however, EPA is expected to release and implement Federal Green Completion

[10] Koch, W. US forecasts natural gas boom through 2040. USA Today. December 16, 2013. http://www.usatoday.com/story/news/nation/2013/12/16/doe-forecast-natural-gas-boom/4034723/
[11] Jackson R, Vengosh A, New tracers identify hydraulic fracturing fluids and accidental releases from oil and gas operations. Environmental Science and Technology. 48(21). 2014.
[12] Holzman, D. Methane Found in well water near fracking sites. Environmental health perspectives, 119(7):a289, 2011.
[13] DiGuilio D, Wilkin T, Miller C, Oberly G. Investigation of groundwater contamination near Pavillion, Wyoming. Technical Report, US Environmental Protection Agency Office of Research and Development, 2011.
[14] EPA Natural Gas Extraction – Hydraulic Fracturing. http://www2.epa.gov/hydraulicfracturing
[15] EPA, EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources. http://www2.epa.gov/hfstudy/hydraulic-fracturing-water-cycle

requirements in 2015 for newly drilled wells, and the Bureau of Land Management has some authority over drilling on Federal lands in western states.[16] While each state engaged in the oil and gas industry has established their own rules and regulations governing industry practices, the success of these regulations has varied. While success has been inconsistent, the intent of each state's regulatory program has not. Every state strives to create regulations that protect environmental and public health while promoting economic growth.

When carefully crafting these regulations, policy makers have needed to make certain assumptions about the industry, and about those engaged in it. These assumptions include: who will be operating in a play? What is an operator's likelihood of success? And will that operator be able to safely and adequately operate under the intent of the state's regulatory framework? As state regulators weight the economic benefits of fracking against its potential environmental harm, it is important to understand how operator risk plays into the regulatory equation.[17] There is a substantial question in the industry as to whether or not operator size has an influence on regulatory compliance. Some individuals within the oil and gas industry believe that the environmental risk associated with fracking scales inversely with operator size, suggesting that large international companies are much less risky than small independent companies without a large national or international presence.[18]

This paper examines this assumption and begins to shed light on how operator size (as well as other operator attributes) contribute to environmental and compliance risk. It uses an analysis of well and compliance data from two states to draw an inference about operator

[16] EPA's Air Rules for the Oil and Natural Gas Industry. 2012. http://www.epa.gov/airquality/oilandgas/pdfs/20120417summarywellsites.pdf
[17] Eyer J. Does Size Matter? The Effect of Firm Size on Fracking Safety. 2014.
[18] Guilbert, D. Gold, R. As Drillers Move In, Safety Goes Up. Wall Street Journal. April 2, 2013. http://www.wsj.com/articles/SB10001424127887324582804578346741120261384

attributes that predict the likelihood of compliance violations as well as an analysis of the perceptions of industry leaders and stakeholders in an attempt to uncover how prevalent these assumptions are. It is important to understand the relationship between operator size and compliance risk because of the need for policy makers and regulators to adequately and properly consider operator size (as well as other attributes) when crafting regulations. If it is the case that smaller companies are more likely to commit environmental violations than their larger counterparts, it may suggest that states need to factor this into their regulatory framework. However, if this assumption is unfounded, then states may wish to lower barriers to entry for smaller firms in their respective states.

Reducing barriers such as lowering bonding requirements, and impact fees may lower operating costs for firms and provide an opportunity for smaller firms with low profit margins to start an oil and gas company in a state. This may be advantageous for a state because small, homegrown firms may keep more of the revenue from O&G development inside the state's economy. Overall, if the risks associated with certain operator attributes can be brought to light, this information may be used by policy makers to help craft new and revise old regulations. This study intends to answer the question of whether or not operator size is a predictor of state environmental and administrative compliance violations. This question will be addressed using historic oil and gas well inspection and compliance data from two states active in the unconventional oil and gas industry. To accompany a dataset analysis, interviews with relevant industry stakeholders were used to look at general industry trends and assumptions.

Section II of the paper describes the methods used in this analysis. Section III discusses the results of the informational interviews and data analysis. Section IV is a discussion of the

results and an interpretation of their meaning. Section V highlights the relevant conclusions of the study and the implications of the results for policy makers and the industry.

Section II

Methods and Data:

Operator Compliance:

In an attempt to quantify the influence of observable operator attributes on state environmental and compliance risk; operator, well, and compliance data were collected from two states that have been actively engaged in fracking and oil and gas development for at least the last 15 years. Pennsylvania and Colorado were selected as the two example states due to the large number of oil and gas wells in each state[19] and the quality and accessibility of each state's reporting program.[20] For each state, well inspection data for each unconventional well in the state was collected from January 1, 2005 through November 1, 2014. Each well is associated with a state permit and an operator of record.[21] The operator of record is responsible for all events that occur on or at the well site, including the actions of any contractor that the operator of record brings on site. If a well changes ownership during the years of interest, the new owner becomes the operator of record once the permitting has been approved.[22]

Well and well site inspections may occur at any time and are generally routine during the production phase of a well; however, inspections are not mandated at or along monthly or yearly

[19] From 2005 to 2014, Pennsylvania has had 11,572 unconventional wells inspected. From 2005 to 2014, Colorado had 17,494 unconventional wells inspected.
[20] Pennsylvania and Colorado each have reporting mandates, however, there are some concerns about the accuracy of these reporting systems.
[21] 25 Pa. Code § 78.11-33
[22] 25 Pa. Code § 78.13-15

intervals in either state.[23] However, inspections are somewhat predictable when major events or changes take place at a well site. Inspections often take place before, during, and after drilling has been completed.[24] The greatest potential for violations occurs during the drilling process of the well due to the presence of fracking fluid, drilling equipment, and produced water onsite. Consequently, this is also the point at which the majority of inspections take place.[25] Inspections may look for compliance with a number of regulations at once, including both environmental and administrative regulations. Administrative violations are incidences in which an operator has violated a regulation; however, that violation does not pose a threat to the environment.

Information on each operator of record active during the time period of concern (2005-2014) was also collected. This information includes specifics regarding attributes of interest of each operator. Aggregating the attributes of each company allowed for the sorting of operators based on the size of each company's operations. Using the size of operation, as well as a number of other attributes, regressions were run to test the influence of operator size on the mean number of violations committed or assessed per inspection.

Pennsylvania:

In Pennsylvania, oil and gas well data was collected from the Pennsylvania Department of Environmental Protection's (DEP) Oil and Gas Program. The DEP collects data and maintains a database containing the location and inspection information of every oil and gas well drilled or permitted in the state.[26] The organization also collects and manages the state's

[23] PA 78 P.S. § 78.902
[24] PA 78 P.S. § 78.902
[25] Eyer J. Does Size Matter? The Effect of Firm Size on Fracking Safety. 2014.
[26] Pennsylvania Department of Environmental Protection. Oil and Gas Reports. 2014. http://www.portal.state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297

compliance reports for wells drilled in the state.[27] Under the Pennsylvania Oil and Gas Act,[28] Coal and Gas Resource Coordination Law[29], and PA Act 13 of 2012[30] the authority to regulate and inspect the oil and gas industry has been delegated to the PA DEP. According to PA Act 13, the department may make inspections, conduct tests or sampling, and review records pertinent to a matter under investigation.[31] In order to do this, an authorized agent at all reasonable times may enter and examine any involved property, facility, operation or activity.[32] The owner, operator, or other person in charge of the property or facility under the chapter, upon presentation of identification for the purpose of inspection, must provide free and unrestricted entry and access to the property and facility.[33]

With regards to the type and frequency of inspections conducted by the DEP, the department is not obligated by state regulation to conduct a minimum or maximum number of inspections per year, or over a certain period of time.[34] However, the Department does intend to conduct inspections in accordance with the following table.[35]

[27] *Id.*
[28] PA Oil and Gas Act, 58 P.S. § 601.101-601.605
[29] PA Coal and Gas Resource Conservation Law, 58 P.S. § 501-518
[30] PA ACT 13 (2012)
[31] 58 P.S. § 3258(a)
[32] 58 P.S. § 3258(a)
[33] 58 P.S. § 3258(b)
[34] PA 78 P.S. § 78.902
[35] PA 78 P.S. § 78.903

Table 1. Frequency of Inspections in Pennsylvania.

Frequency of Inspections	
The Department, its employees and agents intend to conduct inspections at the following frequencies:	
1	At least once prior to the issuance of a permit, if a waiver or exception is requested by the permit applicant.
2	At least once in verifying or resolving objections or determining the Department's response to objections, when objections are raised to a permit application.
3	At least once during each of the phases of siting, drilling, casing, cementing, completing, altering and stimulating a well.
4	At least once during, or within 3 months after, the time period in which the owner or operator is required to restore the site, after drilling the well.
5	At least once prior to the authorization to use an alternate method for plugging, casing or equipping the well.
6	At least once during the periods that an alternative method for plugging, casing or equipping the well is being used or installed.
7	At least once when a well is being reconditioned or repaired or when casing is being replaced.
8	At least once prior to a well being granted inactive status.
9	At least once during the plugging of the well.
10	At least once during, or within 3 months after, the period in which the owner or operator is required to restore the site, after the well is plugged or abandoned.
11	At least once before the bond or other financial security is released.
12	At least once a year, if there is onsite brine disposal or residual waste disposal subject to the statutes referenced in § 78.902 (relating to policy).
13	At least twice a year if the well is located in a gas storage reservoir or in a gas storage reservoir protective area.
14	At least once a year to determine whether compliance with the statutes administered by the Department has been achieved.
15	If there is a violation, at least once to determine whether the violation has been corrected, or whether there is a continuing violation.
16	At least once, in response to a complaint.

In short, the PA DEP has the authority to inspect a well site whenever a new event occurs at the site and intends to inspect every well at least once a year. However, the statutes and regulations do not force or command the DEP to conduct specific inspections. In fact, the

Administrative code contains a provision limiting the inspections of the Department's Oil and Gas Program to be subject to the availability of personnel and financial resources.[36]

The DEP manages state inspectors and sends them out to conduct inspections when the Department deems it pertinent. The DEP has the authority to hand out violations during an inspection if the inspector finds an issue that is not in compliance with the state's regulations. An inspector may level an administrative or an environmental violation. Administrative violations are violations generally dealing with issues related to paperwork and recordkeeping, while environmental violations are infractions that could lead to environmental or public health damage. Following an inspection, the inspector reports back to the Department the results of the inspection and the Department may then levy a fee for violations or impose some other constraint on the operator's actions.[37] Finally, the DEP will publish the inspection results on the department's state website for public viewing.[38]

For this study, DEP well inspection data, published on the Department's website, was used to analyze the compliance histories of individual operators within the state. From this data set, the number of total inspections (administrative and environmental)[39] conducted for unconventional hydraulically fractured wells was collected as well as the number of violations associated with those individual inspections between January 1, 2005 and November 1, 2014. Each inspection was linked to an individual operator of record. Information on each of the 103 operators active in PA during this time was collected and the following attributes were recorded from the Internet and market research about each firm. Information was collected on:

[36] PA 78 P.S. § 78.906
[37] PA 58 § 2308, § 2310, § 3256, § 3260
[38] PA Department of Environmental Protection. Oil and Gas Reports. http://www.portal.state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297
[39] Total inspections include: Administrative, complaint, construction, compliance, drilling, follow-up, incident, routine, pre-operation, plugging, and site restoration.

organizational structure of the firm, market cap, multi-state operations, location of headquarters, year of incorporation, PA starting date, years of operation in PA, international operations, and total number of wells owned.

Table 2. Example of attributes collected for PA operators of record.

Operator	Anadarko	Alliance Petroleum	T&F Exploration
Public/Private	Public	Private	Private
Market Cap	$38,110,392,751	0	0
Multi-State	yes	yes	no
Headquarters	TX	OH	PA
Year of Incorporation	1959	1985	1998
PA starting date	2008	2009	2009
Years of Operation in PA	7	1	6
International	yes	no	no
Total Wells	15000	3764	6

Using these attributes, each operator was assigned a size designation based on a weighted score of attribute values: the larger the operator score, the larger the firm. Companies were separated into three size bins based on attribute score. Small firms = 1, Medium firms = 2, and Large firms = 3.[40]

[40] Appendix 7

Table 3. Example of PA size weighting system.[41]

Operator	Number of States	Year Incorporated	International	Public / Private	Market Cap	Number of Inspections	Sum	Size
ANADARKO LLC	4	1.5	2	2	4	1.5	15	**Large**
ALLIANCE PETROLEUM	2.5	1.5	0	0	1	1	6	**Medium**
T & F EXPLORATION LP	1	1	0	0	1	0.5	3.5	**Small**

The attributes used to calculated operator size were: the number of states the operator was active in, the number of years the company has been active, whether or not the company is international, whether or not the company is public or private, the company's estimated market cap, and the number of inspections of a company's wells between 2005 and 2014. The list below explains the attributes used to calculate a company's size.

- *Number of States:* The number of states a company is active in. This is important because the more states a company is involved in may be an indicator that the company has substantial resources and is therefore potentially a larger company than a firm active in only one or two states. Data obtained from operator websites.
- *Year Incorporated:* The number of years from 2014 that the company has been active. This may be relevant because newer companies are less likely to have had the time to expand in size like older companies have. Data obtained from operator websites.
- *International:* Whether or not a company has international oil and gas operations. International or multinational companies are more likely to have greater capital resources than smaller companies and therefore would be more likely to be larger than strictly domestic companies on average. Data obtained from operator websites.
- *Public/Private:* Whether or not the company is publicly held. Public companies on average are thought to be larger than private companies in the oil and gas industry. Public companies have access to large amounts of capital and are hypothetically capable of expanding more rapidly than private companies. Data gathered from operator websites.
- *Market Cap:* The estimated market cap for public companies. Market cap data provides information on the value of all of the assets of a company. Larger companies generally have more assets. Data gathered from Yahoo Finance on December 15, 2014.
- *Number of Inspections:* The number of inspections of an operator's wells in PA. A larger number of inspections may indicate that the company has been active and established for a number of years and has many wells. Data gathered from the PA DEP.

[41] Small (1-6), Medium (6-13.5), Large (14-18)

Using the size ranking and associated attributes, a negative binomial regression model was used to estimate the effect of firm size (as well as complimentary other attributes) on operator compliance at oil and gas well sites in PA. A negative binomial regression was used because of the nature of the data collected. The number of violations committed per inspection can be classified as count data and is not a continuous variable. With discrete count data, a poisson model is generally used to test the likelihood of the occurrence of an event. However, in this instance, the data collected does not fit the distributional assumption that the conditional mean of the data equals the conditional variance. In Pennsylvania over 50,000 inspections were conducted between 2005 and 2014, and over 40,000 of those inspections resulted in the occurrence of no violation. Due to extreme over-dispersion, the data does not fit the distributional requirements of a standard poisson model. If the conditional distribution of the outcome variable is over-dispersed, the confidence intervals for the negative binomial are likely to be smaller than a comparable poisson model.[42] Due to this over-dispersion, a negative binomial regression was run instead due to the fact that the negative binomial model allows for over-dispersion by estimating a parameter that separates the conditional mean and conditional variance.[43]

The treatment effect in this regression is the size of the firm that owns or operates the unconventional well at the time of inspection. While operator size is the treatment, the data was collected at the well level. Therefore, there was a mismatch in the data between the hierarchical level of the treatment and the point at which the data was collected. In order to ensure independence among observations, the data was clustered at the operator level. Clustering at the

[42] Stata Annotated Output: Negative Binomial Regression. Institute for Digital Research and Education. UCLA. Accessed 2015. http://www.ats.ucla.edu/stat/stata/output/stata_nbreg_output.htm
[43] Eyer J. Does Size Matter? The Effect of Firm Size on Fracking Safety. 2014

operator level ensures that all operators of the same size class are viewed as a single group. When this is done, there is independence at the operator level and corresponding dependence at the well level. Doing this adjusts the standard errors, inflating them to account for differences among operators within the same size class.

Using the negative binomial model, the mean number of violations expected to be issued at a well during an inspection of operator j (y_j) is modeled as

$$y_j = \beta_0 + \beta_1(\text{size\_2}_j) + \beta_2(\text{size\_3}_j) + \beta_3(international_j) + \beta_4(numberofstates_j) + \beta_5(headquarters_j) + \varepsilon_j$$

where,

- y_j is the likelihood of committing a violation during an inspection (mean number of violations per inspection)
- β_1(size_2) is the treatment effect of medium sized firms on the likelihood of violations
- β_2(size_3) is the treatment effect of large sized firms on the likelihood of violations
- β_3(international) is the effect of international status of operator j as of 12/1/2014.
- B_4(numberofstates) is the effect of the number of states operator j is active in as of 12/1/2014
- B_5(headquarters) is the effect of whether or not company j has its corporate headquarters in PA (1/0)
- ε_j is the error term

The response variable (y_j) in this model is the predicted mean number of violations assessed to an operator during any individual inspection. The results of this model should indicate the predictive importance of the variables; size, number of states in operation, location of

headquarters, and international on the number of violations assessed or committed per inspection.

In order to correctly identify the treatment effect on the likelihood of violations in this negative binomial model, the model requires that the conditional distribution of our error terms has a mean of zero, the observations used are independently and identically distributed, there are no significant outliers, the variance of the error terms are constant, and perfect multicollinearity does not exist.

Colorado:

In Colorado, The Colorado Oil and Gas Conservation Act,[44] authorizes the Colorado Oil and Gas Conservation Commission to carry out and enforce oil and gas rules and procedures in the state.[45] One important stage in enforcing the Oil and Gas Conservation Act is to inspect and monitor well sites on private land, as well as land owned by states and local governments for regulatory compliance.[46] The Act charges the Colorado Oil and Gas Conservation Commission (COGCC) with the regulatory authority to make rules and regulations to implement and enforce the nature of the Act.[47] The COGCC or the Colorado Air Pollution Control Division (APCD) inspect the majority of oil and gas wells in CO.[48] The COGCC regulates the physical oil and gas wells, while the APCD monitors air quality. The COGCC is required by statute to develop Colorado's oil and gas resources in a manner that is consistent with the protection of public

[44] C.R.S. § 34-60-101 to 130, (2014)
[45] C.R.S. § 34-60-104, (2014)
[46] The BLM has concurrent authority, along with the COGCC, to inspect federal oil and gas sites.
[47] C.R.S. § 34-60-101 to 130, (2014)
[48] Colorado Legislative Council Brief. Issue Brief: Inspections of Oil and Gas Development. (2013) http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251915389800&ssbinary=true

health, the environment, and wildlife resources.[49] However, the agency is not required by statute to inspect all wells throughout the state on a routine or periodic basis.[50] In accordance with this directive, COGCC inspectors attempt to inspect wells when new activities occur at them, as well as inspect every well in the state every three years.[51]

From 2005 through 2012, Colorado inspectors averaged approximately 1,000 well inspections per year. However, there were less than 15 field inspectors working for the department during that time.[52] Meanwhile, during this time period, the number of wells in CO increased from 29,000 to over 48,000. While the number of field inspectors slowly increased with the number of wells in the state, over two-thirds of the wells in the state were not being inspected yearly. In 2013, the Commission increased the number of inspectors to 23, but the enforcement authority was still only able to inspect 19,084 out of a possible 48,000 wells.[53] To help to deal with this lack of enforcement and help direct the Commission on how to utilize its limited resources, the Colorado legislature enacted SB 13-202, which requires the COGCC to use a risk-based strategy for inspecting oil and gas locations in the state.[54] This strategy directs inspectors to target the operational phases of an oil and gas well most likely to result in environmental contamination. In theory this should focus inspections on the most high-risk areas of operation, but the legislation does not indicate how an inspector should judge or evaluate risk.

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[49] *Id.*
[50] *Id.*
[51] *Id.*
[52] EarthWorks http://www.earthworksaction.org/images/uploads/Colorado-inspection-data-chart-673x468.gif, COGCC Annual Reports to Water Quality Control Commission. 2011.
[53] Colorado Legislative Council Brief. Issue Brief: Inspections of Oil and Gas Development. (2013) http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251915389800&ssbinary=true
[54] Colorado Legislative Council Brief. Issue Brief: Inspections of Oil and Gas Development. (2013) http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251915389800&ssbinary=true

Considering the limited personnel resources available to the COGCC, this presents an opportunity for inspectors to pick and choose which wells and operations are the most risky.

In combination with Colorado's small and underfunded oil and gas monitoring program, the administrative regulations encourage operator self-reporting to fill-in inspection gaps. Pursuant to Rule 523(e), a Colorado operator who maintains a regulatory compliance program[55] and voluntarily discloses to the Director a violation of the Oil and Gas Conservation Act, or any Commission rule, order, or permit discovered as a direct result of such a program will have a rebuttable presumption of a penalty reduction, of at least 35% for a disclosed violation, if certain criteria are met.[56] Under this program, a substantial number of violations reported to the regulatory body are done so by self-reporting. The state's regulations provide an incentive for operators to self-report; however, there is no guarantee how accurate or effective these self-reporting programs are.

The COGCC collects all of its inspection and self-reported data and publishes the statistics on the COGCC's public website. The COGCC collects data and maintains a database containing the location and information of every oil and gas well drilled or permitted in the state.[57] The organization also collects and manages the state's compliance reports.[58] From these data sets, the number of total inspections[59] conducted for unconventional hydraulically fractured wells was collected as well as the number of violations (both environmental and administrative) associated with those individual inspections.

[55] State program designed for oil and gas operators to illustrate how they intend to comply with state regulations. Rule 100.
[56] CO admin code Rule 523(e)(1)
[57] Colorado Oil and Gas Conservation Commission. http://cogcc.state.co.us/
[58] Colorado Oil and Gas Conservation Commission. http://cogcc.state.co.us/
[59] Total inspections include: Administrative, complaint, compliance, drilling, spill, routine, pre-operation, plugging, and remediation.

As in Pennsylvania, each inspection was linked to an individual operator of record. Information on each of the 170 operators' active in CO between 2005 and 2014 was collected and the following attributes of each firm were recorded from internet and market research. Information was collected on: organizational structure, market cap, multi-state operations, location of headquarters, year of incorporation, number of wells in CO, international operations, and total number of owned wells.

Using these attributes, each operator was assigned a size designation based on a weighted score of attribute values: the larger the operator score, the larger the firm. As in Pennsylvania, companies were separated into three size bins based on attribute score. Small firms = 1, Medium firms = 2, and Large firms = 3.

Table 4. Example of CO size weighting system.

Operator	Number of States	Year Incorporated	International	Public / Private	Market Cap	Number of Inspections	Sum	Size
BP America Production Company	4	1.5	2	2	4	3	16.5	Large
Elm Ridge Exploration Company LLC	2.5	1	0	0	1	2	6.5	Medium
Fees Jr and Son Oil and Gas	1	1.5	0	0	1	1	4.5	Small

- *Number of States:* The number of states a company is active in. This is important because the more states a company is involved in may be an indicator that the company has substantial resources and is therefore potentially a larger company than a firm active in only one or two states. Data obtained from operator websites.
- *Year Incorporated:* The number of years from 2014 that the company has been active. This may be relevant because newer companies are less likely to have had the time to expand in size like older companies have. Data obtained from operator websites.
- *International:* Whether or not a company has international oil and gas operations. International or multinational companies are more likely to have greater capital resources than smaller companies and therefore would be more likely to be larger than strictly domestic companies on average. Data obtained from operator websites.

- *Public/Private:* Whether or not the company is publicly held. Public companies on average are thought to be larger than private companies in the oil and gas industry. Public companies have access to large amounts of capital and are hypothetically capable of expanding greater than private companies. Data gathered from operator websites.
- *Market Cap:* The estimated market cap for public companies. Market cap data provides information on the value of all of the assets of a company. Larger companies generally have more assets. Data gathered from Yahoo Finance.
- *Number of Inspections:* The number of inspections of an operator's wells in CO. A larger number of inspections may indicate that the company has been active and established for a number of years and has many wells. Data gathered from the COGCC.

Using the size ranking and associated operator attributes, a negative binomial regression model was run to estimate the effect of firm size (as well as other operator attributes) on operator compliance at oil and gas well sites in Colorado. A negative binomial regression was used because of the over-dispersed nature of the count data collected. While there were over 81,000 inspections between 2005 and 2014, over 90% of those inspections were conducted without a reported violation. Due to the extreme over-dispersion associated with so many zeros in the count data, the data does not fit the distributional requirements of a standard Poisson model. Due to this over-dispersion, a negative binomial regression was run instead.

A negative binomial regression is an extension of a Poisson model that corrects for overdispersion. If the conditional distribution of the outcome variable is over-dispersed, the confidence intervals for the negative binomial are likely to be smaller than a comparable Poisson model.[60] A negative binomial model compensates for over-dispersion by estimating dispersion so that it separates the conditional mean and conditional variance.[61]

As in Pennsylvania, the treatment effect in this model is the size of the firm that is the owner/operator of the unconventional well at the time of inspection. In order to ensure

[60] Stata Annotated Output: Negative Binomial Regression. Institute for Digital Research and Education. UCLA. Accessed 2015. http://www.ats.ucla.edu/stat/stata/output/stata_nbreg_output.htm
[61] Eyer J. Does Size Matter? The Effect of Firm Size on Fracking Safety. 2014.

independence among observations, the data was clustered at the operator level to ensure that all operators of the same size class are viewed as a group and that there is independence at the operator level and corresponding dependence at the well level. Doing this adjusts the standard errors, inflating them to account for differences among operators within the same size class.

The mean number of violations expected to be assessed at a well during an inspection of operator j (y_j) is modeled as

$$y_j = \beta_0 + \beta_1(\text{size\_2}_j) + \beta_2(\text{size\_3}_j) + \beta_3(numberofstates_j) + \beta_4(Headquarters_j) + \beta_5(International_j) + \varepsilon_j$$

where,

- y_j is the likelihood of committing a violation during an inspection (mean number of violations per inspection)
- β_1(size_2) is the treatment effect of medium sized firms on the likelihood of committing a violation
- $\beta_2(size\_3)$ is the treatment effect of large firms on the likelihood of committing a violation.
- β_3(numberofstates) is the treatment effect of the number of states that firm j operates in.
- β_4(headquarters) is the treatment effect of operator j having its headquarters within CO.
- β_5(international) is the treatment effect of operator j having international operations.
- ε_j is the error term

The response variable in this model is the likelihood of having a violation assessed to the operator during any individual inspection. The results of this model indicate the predictive importance of the variables, size, location of headquarters, international component of company, and the number of states an operator is active.

In order to correctly identify the treatment effect on the likelihood of violations in a negative binomial regression, the model requires that the conditional distribution of our error terms has a mean of zero, the observations are independently and identically distributed, there are no significant outliers, the variance of the error terms are constant, and perfect multicollinearity does not exist.

Industry Assumptions: Interviews with Stakeholders:

To better understand how the supposed risk between operators of different sizes is perceived by those actively involved in the industry, a series of informational interviews were conducted with relevant stakeholders and industry experts. 14 individuals were interviewed from different perspectives in and around the industry. Individuals were interviewed from environmental groups, state regulators, small oil and gas operators, and representatives of large operators. These four groupings of individuals and firms can be thought of as being the four main groups of stakeholders concerned with oil and gas activities at the well site. While they are certainly not the only groups affected or interested in unconventional oil and gas development, their voices are the loudest and most politically influential. It is also possible that the views of other groups outside of these four are encompassed in the perspectives of the groups interviewed here.

These four groups are distinct because of their differing approaches and opinions towards the oil and gas industry. Environmental groups are more likely to be concerned with environmental protection than efficiency of extraction, while oil and gas companies may be more interested in feasibility and operational bottom lines than state regulators. While they may all be

experts in the industry, they potentially address industry questions and problems from different perspectives.

By interviewing individuals from these four interest groups, a modest perspective of the industry can be gathered and some potential trends may be pulled out. However, with a sample size of only 14 interviews, a comprehensive analysis of the industry as a whole is difficult. The interviews were conducted in person or over the telephone when appropriate.

Interviewees were ask questions regarding their individual views, as well as what the industry as a whole believes are the differences between large and small companies engaged in unconventional gas development.[62] Questions were also asked about the perceived risk of certain types of companies operating within oil and gas industry and the likelihood of those companies to commit environmental and administrative violations. Following questions about perceived relative compliance risk of companies of different sizes, individuals were asked about the purpose of state regulations and the efficiency and effectiveness of state regulatory programs.

With regards to the strength and effectiveness of regulatory programs, interviewees were asked about the regulatory capabilities of state regulators and the consistency of the interpretation and implementation of regulations by inspectors. Individuals were asked whether or not regulatory agencies are capable of regulating companies of differing sizes equally and if inspectors interact with large and small companies the same way.

Finally, those involved in the informational interviews were asked about the accuracy of the compliance reporting programs that states such as Pennsylvania and Colorado use to keep the

[62] Appendix 8. Copy of questions posed to interviewees

public informed of oil and gas issues. These types of datasets are the datasets that are being used in this analysis to quantify the effect of operator size on compliance.

Table 5. Example of questions asked during informational interviews.[63]

Number	Question
1	- Are there discernable differences between operators of different sizes operating at the well site in the unconventional oil and gas industry?
2	- Does the industry perceive there to be any differences in regulatory compliance between small and large companies? Administrative v. Environmental?
3	- Do you, in your professional capacity, believe that there is a difference in compliance between companies of different sizes?
4	- Are state regulatory agencies capable of regulating large and small processors equally?
5	- How accurate are state violation reporting programs and are these programs evenly enforced?

The human subjects used for these interviews were collected using the interviewer's personal contacts in the oil and gas industry. A snowball sampling technique was then used to network with individuals in each of the four groups willing to participate in the study. While the individuals sampled do not constitute a random sample of the four stakeholder perspectives, they do provide an example subsample of the four stakeholder groups. While it is statistically preferable to randomly sample the population of these groups, the realities of the industry and the responsiveness of stakeholders made this difficult for the interviewer.

Within the environmental group, individuals with experience working on fracking issues in Pennsylvania, Colorado, and North Carolina were sampled. In the regulator group, current or former state regulators were consulted from Pennsylvania and North Carolina. Representatives

[63] Full list of questions can be found in Appendix 8

of small and large operators that are or have been operational in Colorado and Pennsylvania were also interviewed during the study. Stakeholder responses were then qualitatively analyzed to look at general trends in perception among stakeholder groups.

Section III

Results:

Stakeholder responses:

Of the 14 individuals interviewed during this study concerning the influence of operator size on environmental risk in the unconventional oil and gas industry, 13 of the 14 indicated that there is a general industry assumption that smaller companies are environmentally riskier than larger companies (Figure 1). The other individual, a representative of a small oil and gas company, responded that this assumption may be the case, but he is not sure.

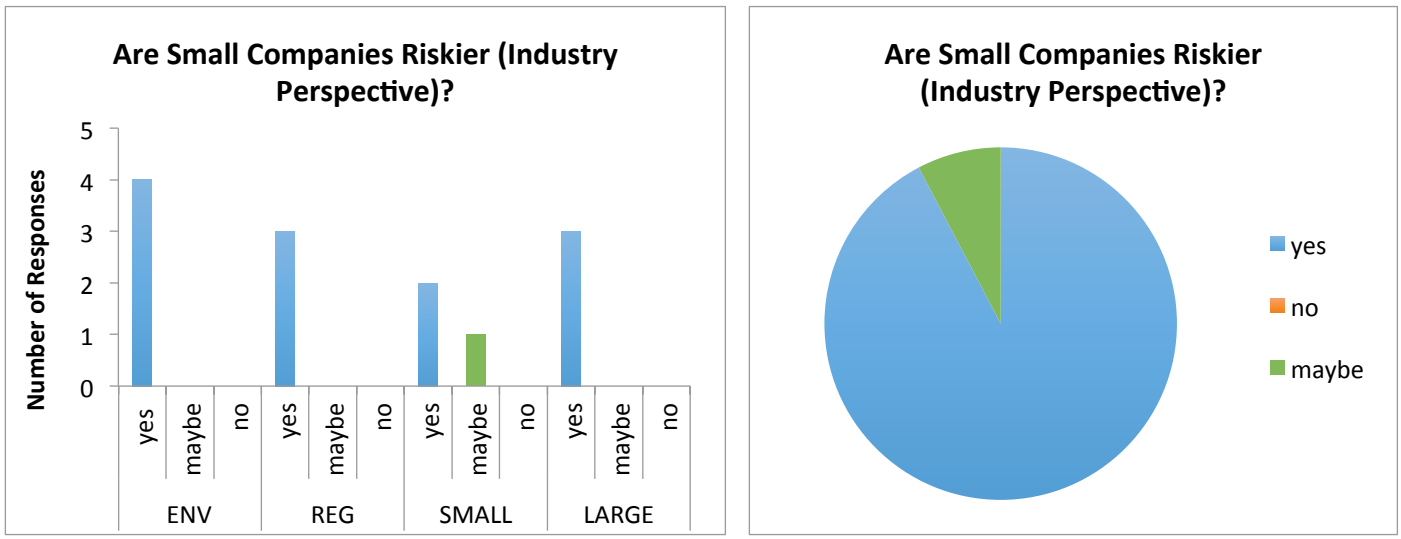

Figure 1. Number of responses to interview question about whether or not the oil and gas industry as a whole assumes that small companies are riskier than larger companies.

This response suggests that there may be a strong assumption among those involved in the oil and gas industry that differences exist between operators of different types and sizes, and that the industry assumes that smaller firms present more risk than larger ones. However, when these same individuals were asked what their own personal beliefs about the riskiness of oil and gas companies of differing sizes, responses were less uniform (Figure 2).

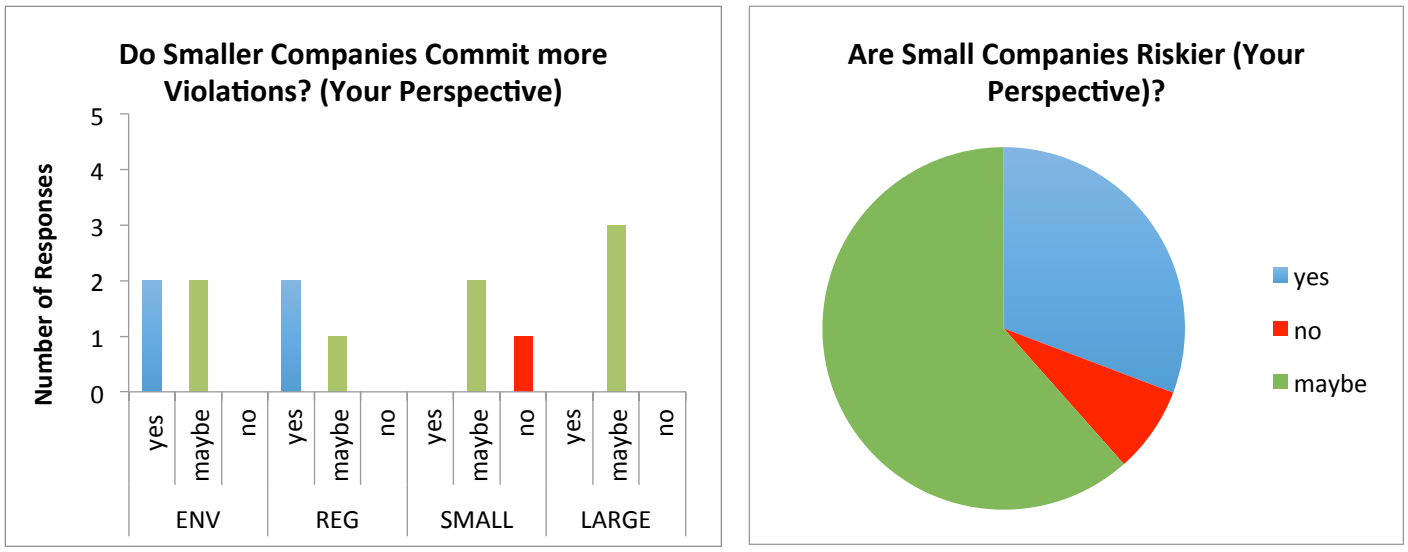

Figure 2. Number of responses to interview question about whether or not the respondent believes that small companies are riskier than larger companies.

The results of Figure 2 suggest there may be much more uncertainty about this assumption at the individual level than at the level of the industry as a whole. The majority of respondents indicated that there may be some level of truth behind this assumption; however, they have not seen any direct evidence suggesting that this is in fact the case. All respondents gave anecdotal evidence as to why larger companies may be safer than smaller ones, however; only four provided a rationale with strong conviction.

For example, multiple environmental representatives and regulators suggested that smaller companies may be more likely to commit/be assessed violations than larger companies due to the fact that these companies generally do not have the technology, expertise, and experience that many larger firms have. Regulators suggested that larger companies have greater access to capital and engineering advancements that would allow them to operate more efficiently and safer than smaller firms without the latest technological advancements.[64] This assumes that new, high priced technologies increase safety in the oil and gas industry and that smaller firms do not have access to this technology.

Interviewees also indicated that an assumption about industry experience and expertise has shaped their view, creating the belief that smaller companies may be more risky than larger firms. Nearly all respondents indicated that it is most likely the case that smaller companies have less expertise than larger ones. As one large operator indicated, large companies have redundant expertise in the sense that they have drilled and operated more of the same types of wells over a longer period of time than many small operators.[65] Along with redundancy, large operators are thought to have the funds to hire the best geologists and the strongest and most experienced labor force.[66] If this is true, then larger companies may be able to use this expertise and long-standing knowledge of the industry to more aptly comply with state regulations.

While these reasons have been provided as anecdotal evidence that larger companies are better able to comply with regulations and are therefore less risky than smaller companies, hard evidence may not currently exist to support this conclusion.

[64] Interviews with REG 1 1/27/15, and REG 2 1/29/15
[65] Interview with LARGE 1 2/20/15
[66] Interview with ENV. 2 1/27/15

When asked whether or not this assumption has been expressed in state regulations across the country, responses were mixed (Figure 3).

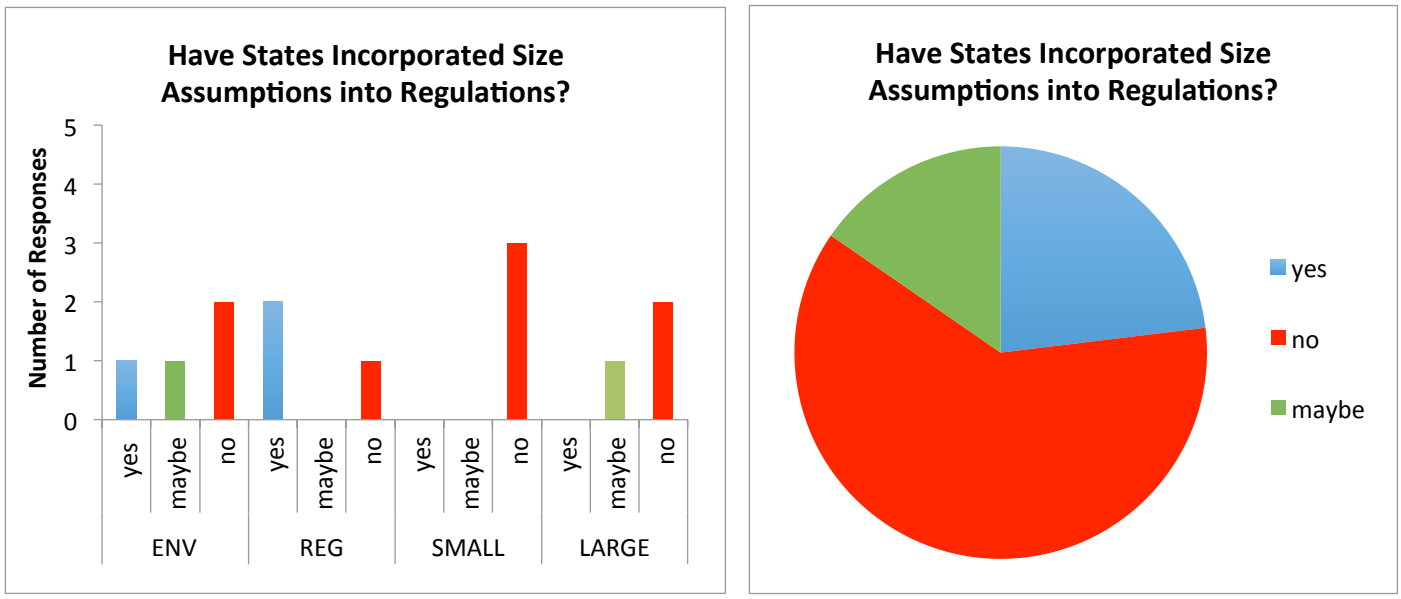

Figure 3. Number of responses to the interview question: Have states incorporated an assumption that smaller companies are more risky into their regulations?

Less than half of those interviewed strongly believed that assumptions about the risks associated with operator size have influenced state regulations. Most individuals did not believe that states have actively crafted regulations aimed to mitigate the supposed risk of small companies. However, a significant number of interviewees reported that some regulations have the effect of being barriers to entry for small operators, yet were not designed for that purpose.[67] These types of regulations include bonding requirements, severance taxes, and impact fees.[68] These results and anecdotal evidence may indicate that although some states may not be actively attempting to mitigate the perceived risk of certain types of companies relative to others, regulations with other intentions may be having this effect.

[67] REG 1 1/27/15, ENV 1 1/29/15, ENV 2 1/27/15
[68] ENV 1, ENV 2, SMALL 1, REG 1

When asked about regulatory regimes and the ability of state programs to regulate effectively in a non-biased manner, all respondents suggested that states have difficulty consistently implementing rules and regulations in the oil and gas industry. When directly asked the question whether or not states regulate all companies equally, only two respondents answered yes. The remaining answers to this question were nearly evenly distributed among maybe and no (Figure 4).

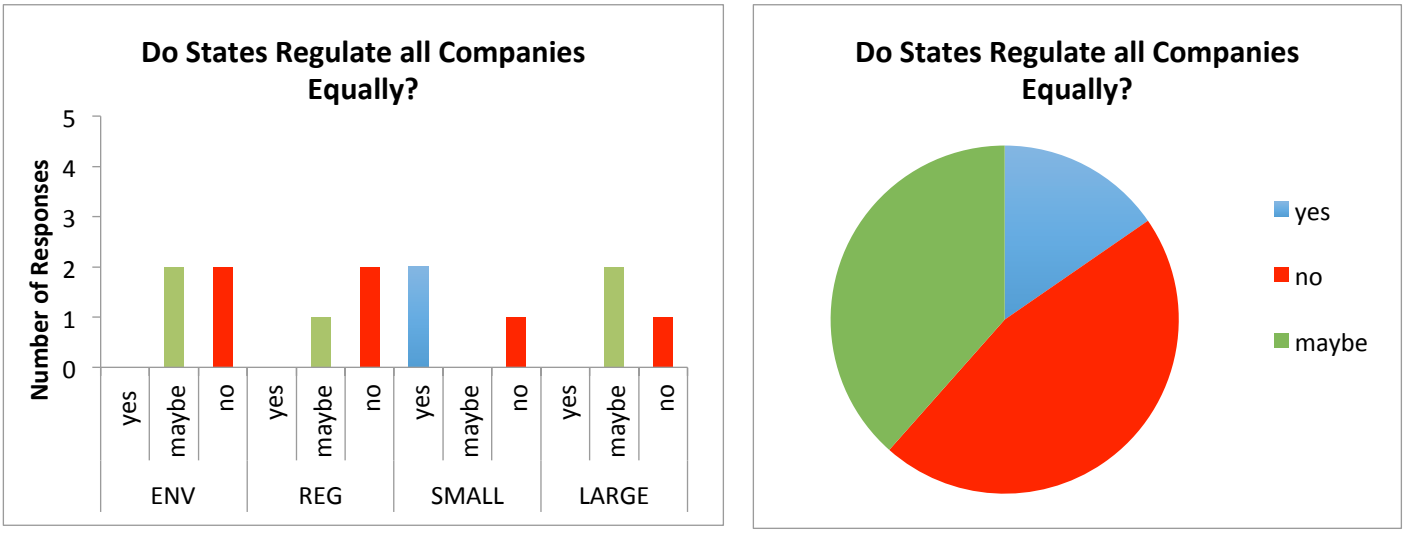

Figure 4. Number of responses to the interview question: Do states regulate all companies equally independent of operator size?

Respondents across stakeholder type indicated that there are significant implementation issues at the state level. All interviewees noted that state regulatory programs are underfunded and overworked, and that regulators are most likely doing good work with their available resources.[69] However, these resources are not sufficient to provide the level of inspection and oversight that the public often demands and that the industry requires. Due to budgetary constraints and a lack of man-hours, all stakeholders indicated that state regulatory programs were lacking in one form or another.

[69] REG 1,2, SMALL 1,2, LARGE 1,2

Many respondents indicated that state programs are likely to regulate company types differently because of this of resource constraint. Some suggested that state regulators would be less likely to fine or issue a violation to large operators for an illegal event than a small operator. An environmental representative and a state regulator suggested that this would manifest itself due to the political strength and pressure of larger companies.[70] Other individuals stated that regulators are more likely to work with large companies to avoid violations than smaller companies due to the large number of wells generally owned by large operators.[71] These individuals believe that if a regulator sees that a large company has an event that would require the administration of a violation, that regulator may be more willing to help the company fix the problem without issuing the violation because that operator could then hypothetically fix that problem on all of his or her other wells in the state.[72] By helping the operator avoid a violation at one well, theory suggests that the regulator could prevent future violations at other wells. Small operators with a fewer number of wells may not be extended this courtesy.[73]

While this sentiment predominantly held through the majority of the interviews, one regulator suggested that administrative violations are lower for small companies when compared to larger companies.[74] This is not due to the fact that small companies are more adept to handle paperwork, but instead due to the idea that regulators are likely to underreport administrative violations from small companies, with the idea of attempting to give these types of companies a break to help them get their foot in the door.[75]

[70] REG 2, ENV 2
[71] REG 1, REG 3, SMALL 1.
[72] REG 1, REG 3, SMALL 1.
[73] REG 1, REG 3, SMALL 1.
[74] REG 1
[75] REG 1

Finally, with respect to the accuracy of state violation and compliance reporting, the overwhelming majority of stakeholders interviewed expressed skepticism about the accuracy of reporting systems (Figure 5). Nearly all interviewees, regardless of stakeholder perspective, indicated that state compliance databases are most likely either incomplete, due to missing data, or skewed due to inspector bias. Most individuals attributed the incomplete nature of the databases to a lack of resources available to the state regulatory agencies tasked with carrying out this objective.[76]

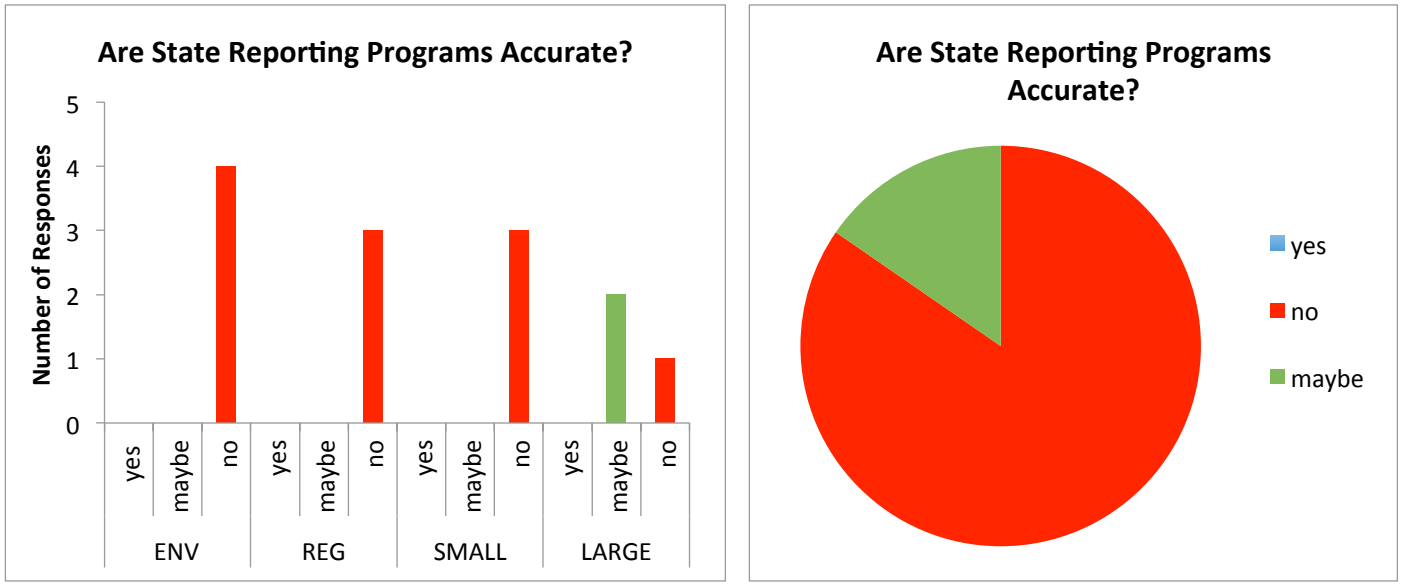

Figure 5. Number of responses to the interview question: Are state reporting programs and databases accurate and representative?

A lack of confidence in state required disclosure databases may indicate that compliance and violation data from these reporting systems are unreliable. However, they are the best data currently available to study compliance trends in the industry.

[76] REG 1, 2 SMALL 1,3, ENV 2,4

Regression Statistics:

In Pennsylvania, the number of unconventional oil and gas wells has dramatically increased since 2005. In 2005, there were only 13 unconventional oil and gas wells in the state; however, the number of wells drastically increased through the end of the decade and begun to slow in recent years (Figure 6). An increase in the number of wells corresponds with an increase in state inspections (Figure 6). Increases in inspections appear to be at a similar rate as increases in wells drilled indicating that the state has been able to stay fairly constant in its inspection regime despite regulatory changes from 2005 through 2012 (Figure 7).

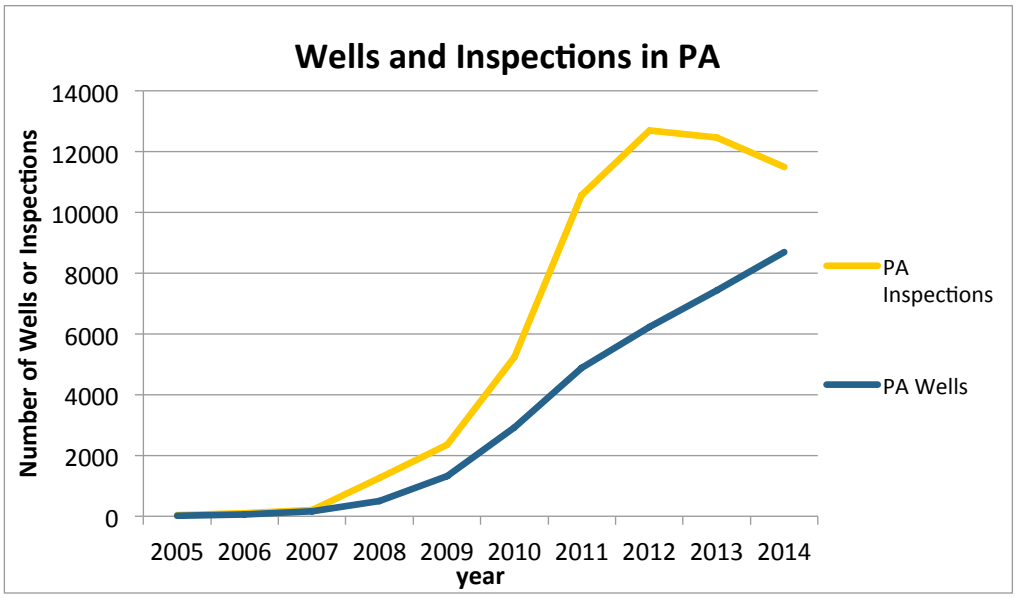

Figure 6. Number of wells and inspections in PA between 2005 and 2014.

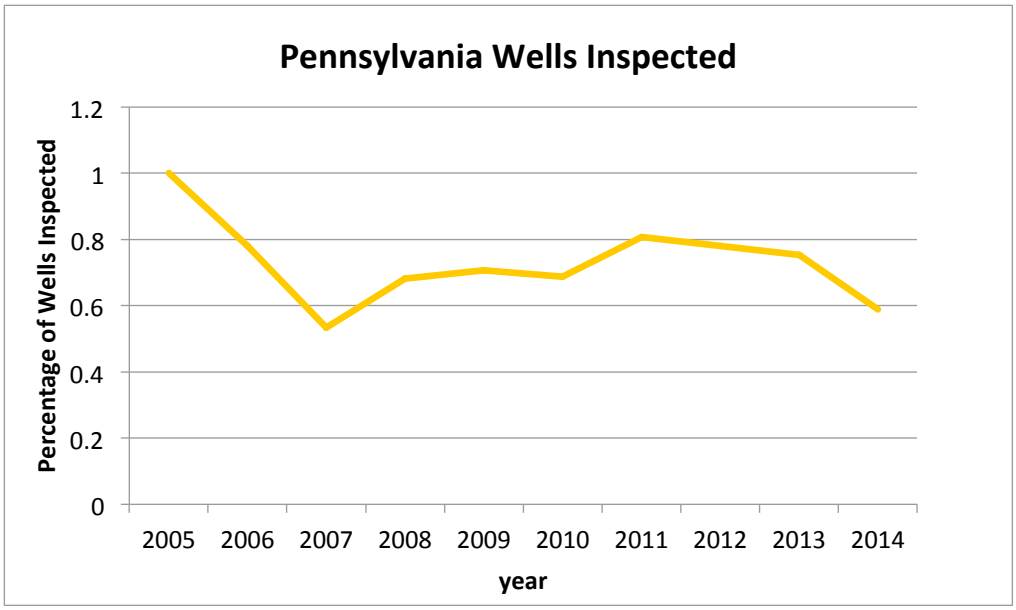

Figure 7. Percentage of Pennsylvania wells inspected from 2005 to 2014.

While there is significant concern about the environmental safety of the hydraulic fracturing industry in the United States, the relative safety of the industry seems to be improving through time. In Pennsylvania for example, within the Marcellus shale formation, Considine et al. (2012) found in their research that there was a 60% decline in environmentally damaging events between 2008 and 2012.[77] This corresponds with a decrease in the total number of violations per inspection from 2006 to 2014 (Figure 8).

[77] Timothy Considine, Robert Watson, Nicholas Considine, and John Martin. Environ- mental impacts during marcellus shale gas drilling: Causes, impacts, and remedies. Technical report, State University of New York at Buffalo Shale Resources and Society Institute, 2012.

Figure 8. Number of violations per inspection in PA from 2005 to 2014. (Industry wide)

From 2006 through 2014, Pennsylvania has consistently attempted to strengthen their oil and gas regulations in response to numerous environmental mishaps and pollution incidences.[78] This strengthening of regulations corresponds with an uptick in the likelihood of violations at an inspection. However, violations peak around 0.25 violations per inspection in the latter months of 2009 and steadily decline to about 0.03 violations per inspection in 2014. While the number of inspections per well has remained fairly constant over this time period (Figure 7), this result may indicates that fracking companies responded to stronger regulations and began acting in a more compliant manner. While the number of inspections per year has stayed somewhat constant over the last four years, the number of violations has fallen dramatically. Considering that PA has strengthened its rules over this time period, it may be the case that unconventional oil and gas development has become less environmentally risky over the last decade. While the industry as a whole in PA appears to be improving by way of compliance, a question still

[78] 2009 and 2011 amendments to 25 Pa. Code § 78-79, PA Act 13 (2012)

remains as to whether or not all operators are improving, or whether some types of operators are more compliant than others.

In Colorado, as in Pennsylvania, the number of wells and inspections has increased at a fairly similar rate. Unlike Pennsylvania, Colorado has a long history of oil and gas development, and has been active in the unconventional oil and gas space for a number of years prior to 2005. In fact, in 2005, the state already had over 25,000 wells in the ground (Figure 9). The number of wells drilled steadily increased over the decade, and by 2014, there were over 50,000 wells in CO (Figure 9). The state's inspection regime has kept pace with this increase in wells (albeit at an inspection level incapable of monitoring every well each year), maintaining an inspection per well ratio around 0.3 for much of time period between 2005 and 2012 (Figure 10). The sharp uptick in inspections in CO in 2013 can be attributed to the implementation in 2013 of two regulatory reform bills, SB 13-202[79] and HB 13-1278[80] and the hiring of more inspectors (Figure 11). These two bills provided more direction for the COGCC in its regulatory efforts and increased funding to the agency. Overall, Colorado has an underwhelming inspection program (only 28 inspectors in 2014), however, this inspection program has stayed relatively consistent over the first 8 years of this study.

[79] CO SB 13-202 (2013)
[80] CO HB 13-1278 (2013)

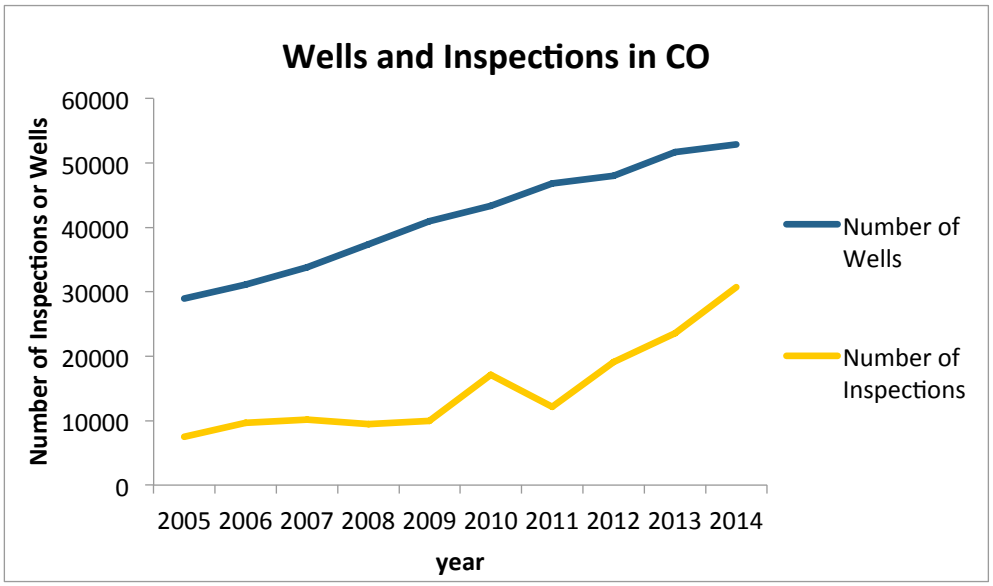

Figure 9. Number of Wells and number of well inspections in CO between 2005 and 2014

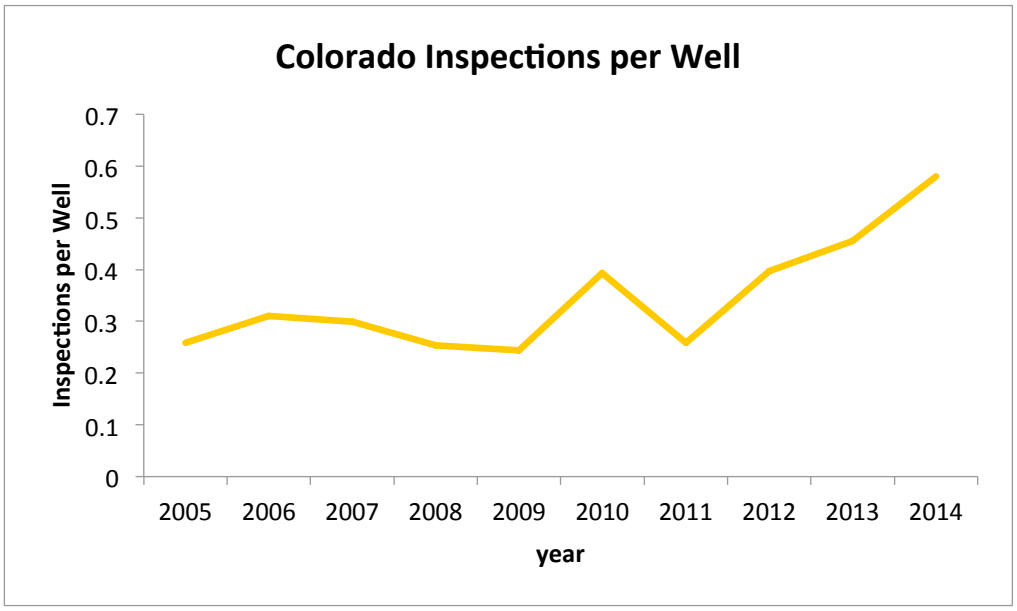

Figure 10. Number of Inspections per well in Colorado from 2005 to 2014.

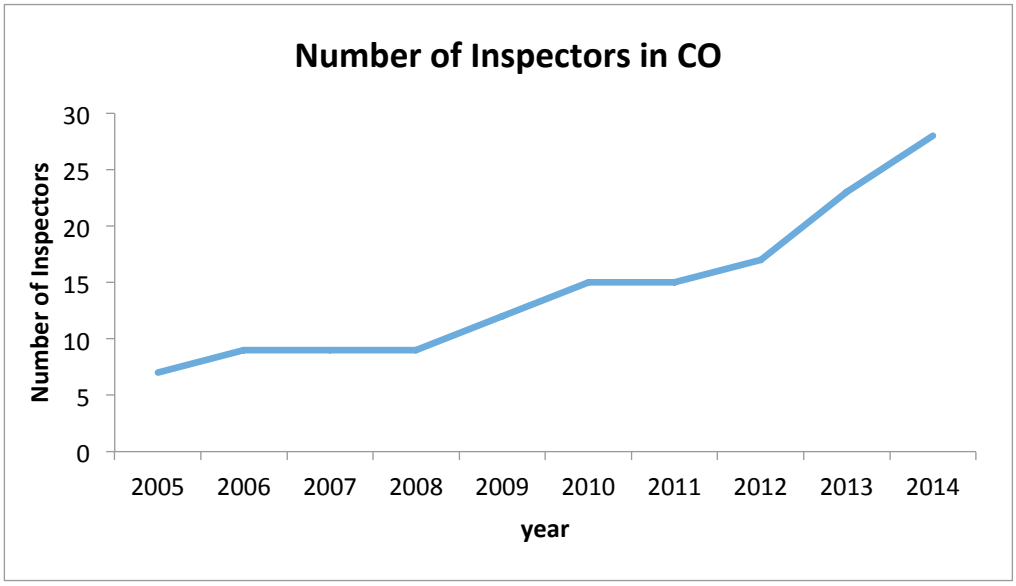

Figure 11. Number of Inspectors working for the COGCC from 2005 to 2014

Colorado:

The statistical analysis and negative binomial regression of compliance and violation data from Colorado suggests that all companies engaged in shale gas development and production are not equally compliant. 170 companies have operated unconventional oil and gas wells in Colorado between 2005 and 2014. Of those 170 companies, 74 have been designated as "small" companies, 52 as "medium" companies, and 43 as "large" companies from the size scoring system described earlier (Figure 12). While there may be fewer large operators than small operators in CO, larger operators own significantly more wells than medium or small firms, and consequently have many more inspections than those firms (Figure 13).

The mean number of violations committed during an inspection for each of the three groups of operators between 2005 and 2014 appears to differ. Smaller companies appear to have a larger number of violations per inspection when compared to medium or large companies;

however, the variance of each group is quite high due to large variation within groups and the presence of outliers (Table 6).

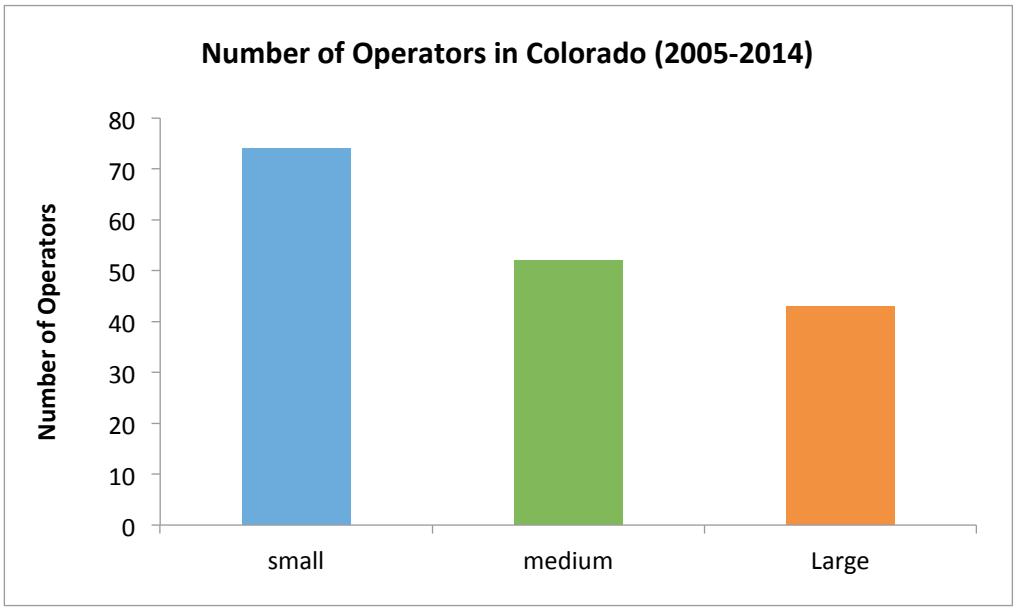

Figure 12. Number of operators in Colorado by operator size. (2005-2014)

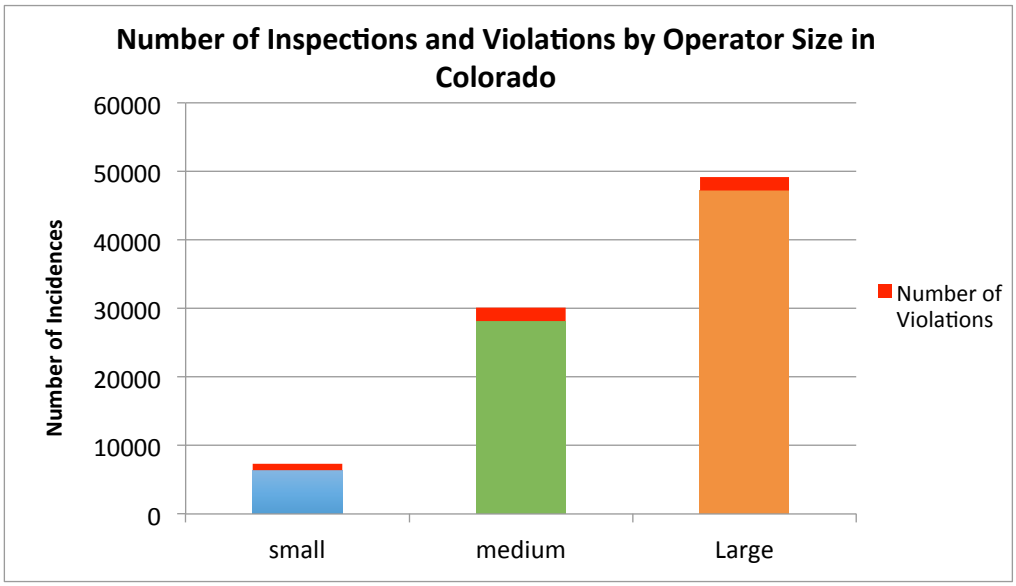

Figure 13. Number of Inspections and violations by operator size in Colorado. (2005-2014)

Table 6. Colorado mean number of violations per inspection by operator size

Size	Operators	Mean	Variance	Min	Max	Inspections
1	74	0.1582	0.4115	0	1.0126	6296
2	52	0.0706	0.2340	0	0.3854	27935
3	43	0.0411	0.1345	0	0.3333	47262

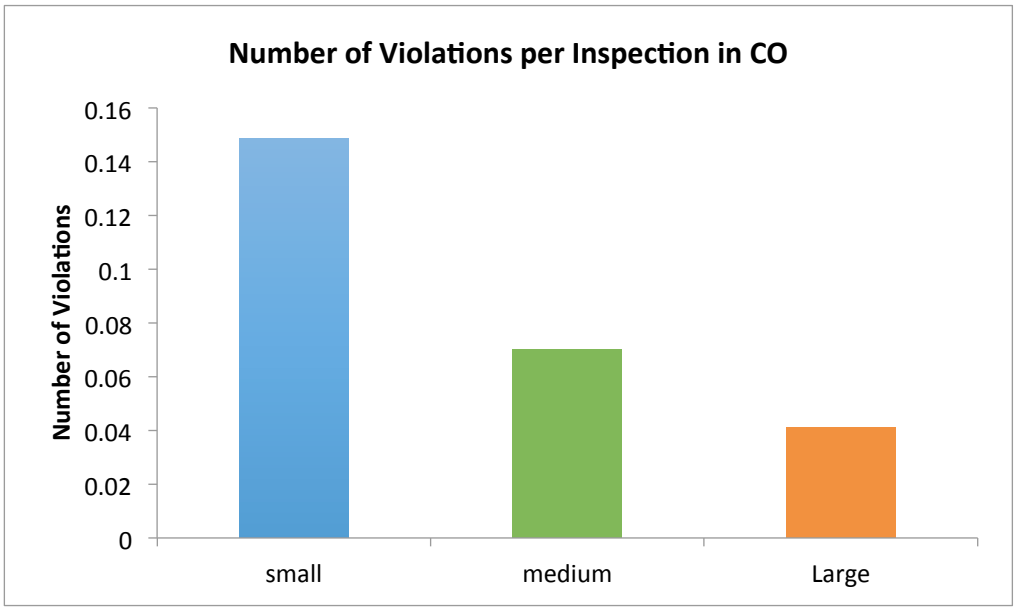

Figure 14. Number of violations per inspection in Colorado by operator size. (2005-2014)

The Colorado data appears to suggest that differences in means exist between operators of different size. Table 6 indicates that the mean number of violations per inspection for small operators (0.1582) is approximately three times greater than the mean number of violations for large operators (0.0411). Medium sized companies (0.0706) appear to fall in the midpoint between small and large companies (Figure 14).

To test whether or not these means are statically significant, a two way anova comparison of means test was run on the likelihood data for each company size. The anova results (Table 7) suggest that the means of the three groups are statistically different from one another ($p<0.000$), however, by itself, company size is not a great predictor of the likelihood of violations or a strong explainer of the variation in violation data ($R^2=0.005$).

Table 7. Anova statistical mean results for CO size data.

Colorado Anova Test of Means Results

Source	Sum of Squares	df	F	p
Model	80.071	2	210.72	0.0000
Size	80.071	2	210.72	0.0000
Residual	15482.8	81490		
R squared	0.005			

To better understand the effect of size and other operator attributes on the likelihood of being assessed a violation during an inspection, a negative binomial regression was run using number of violations per inspection as the outcome variable and operator size as the treatment variable. The explanatory variables used in the negative binomial model were operator size, the number of states the operator is active in, whether or not the company was international, and the location of the company's headquarters. The results of the model suggest that size, international status, location of headquarters, and number of states in operation are all inversely related to the mean number of violations per inspection (Table 8).

Table 8. Negative binomial model for the impact of operator size on compliance in Colorado (2005-2014).

Colorado Negative Binomial Regression

Number of Violations	Coefficient	Marginal Effect
Medium Size	-0.8467** (0.0756)	-0.0983** (0.0287)
Large Size	-1.4941** (0.3315)	-0.1334** (0.0443)
International	-0.1744 (0.2586)	-0.0105 (0.0156)
Number of States	-0.0515** (0.0092)	-0.0031** (0.0006)
Headquarters	-0.5922* (0.3319)	-0.0357* (0.0211)
Observations	78211	

A negative binomial regression model, used to model count data, can provide an estimate of the impact of an individual variable on the number of occurrences of an event. The model for Colorado indicates that all of the variables selected have a negative impact on the occurrence of violations per inspection. With regards to size, the model estimates that an increase in operator size from small to medium leads to a decrease in the log count of violations per inspection by 0.8467 (Table 8). This can be interpreted as the marginal effect of shifting from a small to a medium sized operator, on average, led to a decrease in the number of violations per inspection by 0.0982 holding all else equal (Table 8). This result was highly significant at the 5% confidence level (p=0.001). This result provides a strong reason to believe that there is a trend

towards fewer violations as a company increases in size from a small firm to a medium sized firm.

The results also estimate that an increase in size from a small firm to a large firm may lead to decrease in the log count of violations per inspection of 1.4942 in CO holding all else constant (Table 8). This can be interpreted as the marginal effect of an increase in firm size from small to large is a decrease in the average number of violations per inspection of 0.1334 holding all else equal (Table 8). This effect is statistically significant at the 5% confidence level ($p=0.003$) and indicates that there are significantly fewer violations committed per inspection by large companies compared to small companies. Due to the high significance of the impact of operator size on violations, we can comfortably say that operator size has an impact on the number of violations per inspection in Colorado. Increases in operator size appear to lead to decreases in total violations.

With regards to the impact of the operator's international status on violations, the model suggests that international companies are likely to have fewer violations per inspection than strictly domestic companies. The regression model estimates that a shift from a domestic company to an international firm, holding all else equal, will lead to a decrease in the expected log count of the number of violations per inspection by 0.1744 (Table 8). This can be interpreted as a marginal change from a domestic to an international firm leads to an average decrease in the number of violations per inspection of 0.0105 (Table 8). However, this result was not highly significant ($p=0.501$), indicating that the international nature of a firm does not strongly predict the number of violations per inspection in Colorado.

The location of the company's headquarters also had an impact on the number of total violations per inspection in Colorado. The model predicts that companies whose headquarters are in Colorado, when compared to companies whose headquarters are in other states, are likely to experience a decrease in the expected log count of the number of violations per inspection by 0.5922 holding all else equal (Table 8). This can be interpreted at the margins as a company that has its headquarters in CO is expected to have 0.0357 fewer violations reported per inspection than a company with headquarters outside of the state (Table 8). This result is also not highly significant (p=0.091) at the 5% confidence level; however, it is significant at the 10% level. While not highly significant, the results do suggest that there is a trend in the data indicating that firms headquartered in Colorado are likely to commit fewer violations per inspection than firm firms incorporated outside of the state.

The final variable of interest in this model is the number of states an operator is active in. The model estimates that a one unit increase in number of states will lead to a decrease in the expected log count of the number of violations per inspection by 0.0514 holding all else constant (Table 8). This may be interpreted at the margins as an increase in the number of states in operation by one state will, on average, decrease the number of violations per inspection by 0.0031 (Table 8). This result is highly significant at the 5% confidence level (p=0.000). For this reason, we can assert with confidence that the number of states an operator is active in has a significant impact on operator compliance.

Pennsylvania:

The statistical analysis and negative binomial regression of compliance and violation data from Pennsylvania suggests that all companies engaged in shale gas development

and production are not equally compliant. 103 companies have operated unconventional oil and gas wells in Pennsylvania between 2005 and 2014. Of those 103 companies, 38 have been designated as "small" companies, 30 as "medium" companies, and 35 as "large" companies from the size rankings discussed in the Methods section (Figure 15). While there are a similar number of small, medium, and large firms in the state, large firms own a vast majority of the state's wells. A larger number of wells correspond with a larger number of inspections (Figure 16). According to the data, the mean number of violations committed during an inspection is higher for smaller firms than for medium or large firms (Figure 17). However, this difference is not dramatic, and there is considerable variation in the number of wells owned within the three size groups (Table 9).

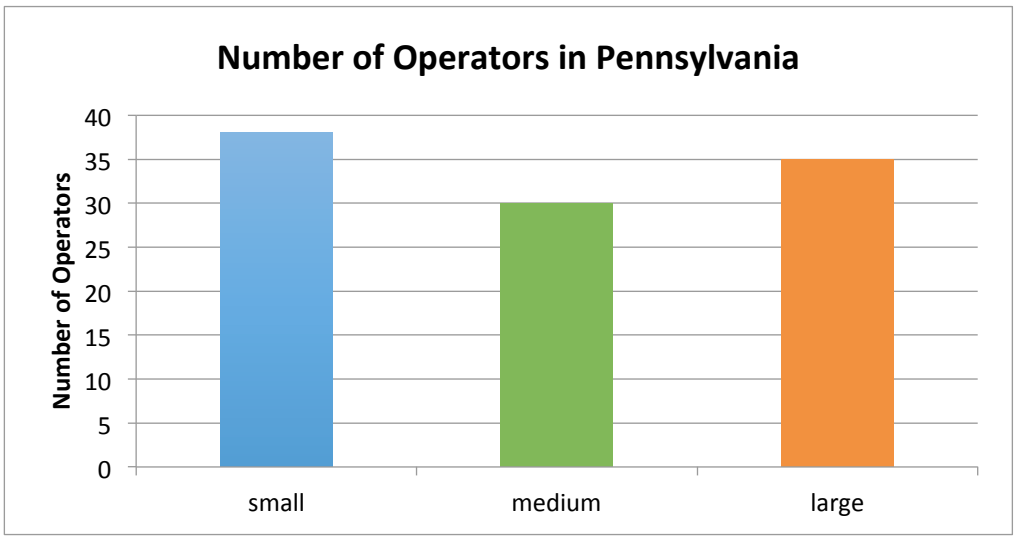

Figure 15. Number of operators of differing size in Pennsylvania between 2005 and 2014.

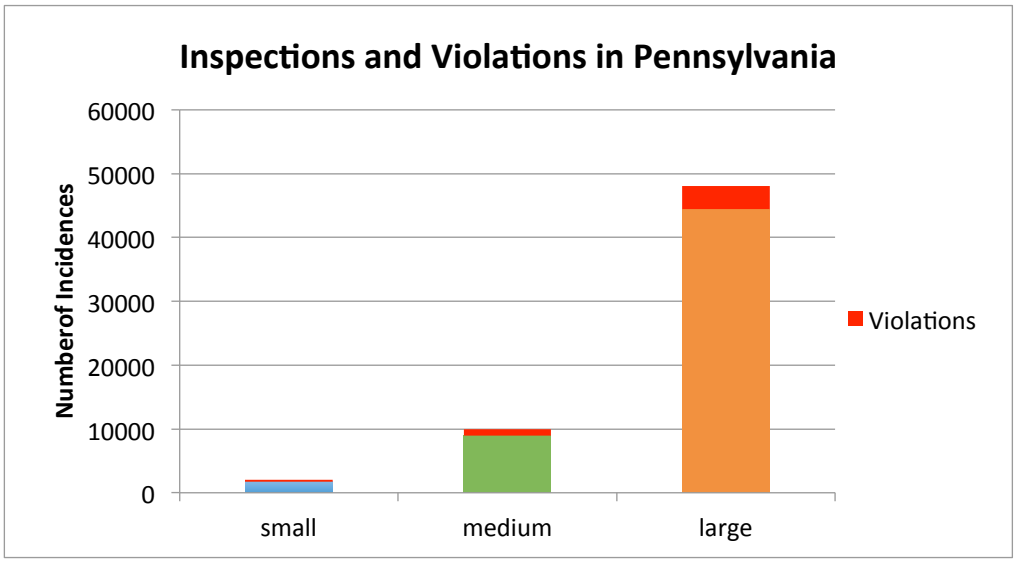

Figure 16. Number of inspections and violations by operator size in PA between 2005 and 2014.

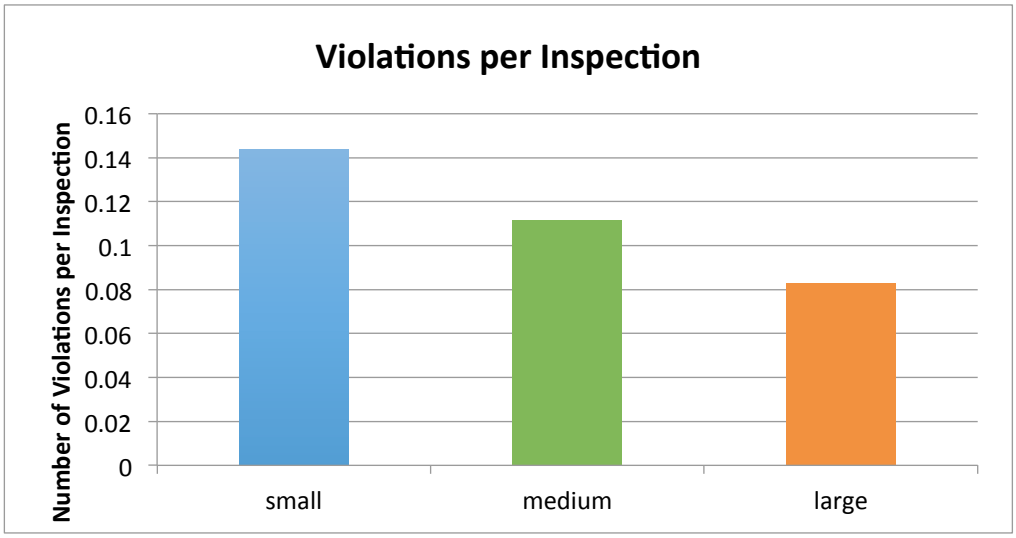

Figure 17. Number of violations per inspection by operator size in PA between 2005 and 2014

Table 9. Pennsylvania mean number of violations per inspection by operator size, 2005-2014

Size	Operators	Mean	Variance	Min	Max	Inspections
1	38	0.1359	0.3079	0	1.200	1766
2	30	0.1132	0.4403	0	0.7073	8941
3	35	0.0808	0.2678	0	0.6083	44426

To test whether or not the differences between these means are statically significant, a two way anova comparison of means test was run on the likelihood data for each company size. The anova results (Table 10) suggest that the means of the three groups are statistically different from one another ($p<0.000$). However, this test does not indicate how the means differ or by how much. Although this test provides interesting insight, company size alone is not a great predictor of the likelihood of violations and does not explain a significant amount of variation in the outcome variable ($R^2=0.007$). For this reason, higher order statistical analysis was used to tease out the impact of operator of record size on the number of violations reported during each inspection.

Table 10. Anova statistical mean results for PA size data.

Pennsylvania Anova Test of Means Results

Source	Sum of Squares	df	F	p
Model	11.927	2	20.07	0.0000
Size	11.927	2	20.07	0.0000
Residual	16378.48	55130		
R squared	0.007			

To better understand the effect of size and other operator attributes on the likelihood of being assessed a violation during an inspection in Pennsylvania, a negative binomial regression was run using the number of violations per inspection as the outcome variable and size as the main treatment variable. The explanatory variables used in the linear regression model were operator size, number of states the operator has active operations in, whether or not the company's headquarters are in PA, and whether or not the company is international. The results of the model suggest that all of the treatment variables are inversely correlated with the mean number of violations per inspection (Table 11).

Table 11. Results from the Clustered Pennsylvania Negative Binomial Regression Model (2005-2014).

Pennsylvania Negative Binomial Regression

Number of Violations	Coefficient	Marginal Effect
Medium Size	-0.2582** (0.0303)	-0.0310** (0.0045)
Large Size	-0.5071** (0.0414)	-0.0542** (0.0058)
International	-0.3603** (0.0329)	-0.0316** (0.0031)
Number of States	-0.0101 (0.0097)	-0.0008 (0.0008)
Headquarters	-0.4464** (0.1691)	-0.0391** (0.0151)
Observations	55133	

A negative binomial regression model, used to model count data, can provide an estimate of the impact of an individual variable on the number of occurrences of an event. The model

indicates that all of the variables selected have a negative impact on the number of violations per inspection. With regard to size, the model estimates that a one-unit increase in operator size from small to medium leads to a decrease in the log count of violations per inspection of 0.2582 (Table 11). This can be interpreted as the marginal effect of shifting from a small to a medium sized operator on average led to a decrease in the number of violations per inspection by 0.0310 holding all else equal (Table 11). Increasing in size from a "small" to a "medium" sized firm appears to lead to a significant decrease in violations per inspection ($P<0.000$). This result is highly significant, and provides reason to believe that medium sized firms commit or are assessed fewer violations per inspection than small firms.

The results also estimate that increasing in size from a small firm to a large firm may lead to a decrease in the log count of violations per inspection of 0.5071 in Pennsylvania (Table 11). This can be interpreted as the marginal effect of shifting from a small to a large sized operator on average leads to a decrease in the number of violations per inspection by 0.0542 holding all else equal (Table 11). This effect is statistically significant at the 5% confidence level ($p<0.000$) and indicates that there is a substantial decrease in the number of violations per inspection for large companies when compared to small companies. Due to the high significance of the impact of size on violations, we can comfortably say that operator size has an impact on the number of violations per inspection. Increases in operator size appear to lead to decreases in total violations.

The model also suggests that an operator's international status has an impact on the number of violations per inspection. The model suggests that an international company is likely to have fewer violations per inspection than a strictly domestic company. The regression model estimates that a shift from a domestic company to an international firm, holding all else equal,

will lead to a decrease in the expected log count of the number of violations per inspection by 0.3603 (Table 11). This can be interpreted as a marginal change from a domestic to an international firm leads to an average decrease in the number of violations per inspection of 0.0315 (Table 11). This result is highly significant ($p<0.000$) and suggests that international companies are less likely to commit or be assessed violations in Pennsylvania than domestic firms.

The location of the company's headquarters also had an impact on the number of total violations per inspection in PA. The model predicts that companies whose headquarters are in Pennsylvania, when compared to companies whose headquarters are in other states, are likely to experience a decrease in the expected log count of the number of violations per inspection by 0.4464 holding all else equal (Table 11). This can be interpreted at the margins as a company that has its headquarters in CO is expected to have 0.0391 fewer violations reported per inspection than a company with headquarters outside of the state (Table 11). This result is also highly significant ($p=0.009$) and suggests that a company whose headquarters are inside of the state of PA is less likely to commit violations than a company headquartered out of state.

The final variable of interest in this model is the number of states an operator is active in. The model estimates that a one unit increase in number of states will lead to a decrease in the expected log count of the number of violations per inspection by 0.0101 holding all else constant (Table 11). This may be interpreted at the margins as an increase in the number of states in operation by one state will, on average, decrease the number of violations per inspection by 0.0009 (Table 11). This result, while interesting, is not significant at the 5% confidence level ($p<0.297$). For this reason, we cannot assert with confidence that the number of states an operator is active in has a significant impact on operator compliance in Pennsylvania.

Section IV

Discussion:

The results of the informational interviews conducted of industry leaders and relevant stakeholders indicate that there may be a general assumption among members of the unconventional oil and gas industry regarding the link between operator size and compliance. Individuals surveyed believe that the industry has as assumption, albeit unsubstantiated by data, that larger companies are inherently less risky than smaller companies engaged in hydraulic fracturing. While most respondents indicated that they believe that the industry has this assumption, the varied responses at the individual perspective level illustrate a current lack of clear and convincing data surrounding this assumption. This paper aims to help begin to clarify some of the thinking surrounding this assumption and provide valuable policy information to regulators moving forward.

Those surveyed for this analysis were a small sample of individuals with experience in the hydraulic fracturing industry from a number of states and geographic regions including Pennsylvania and Colorado. Interviewees did not indicate that there was substantial variation in industry assumptions by geographic or spatial region. For this reason, there is some reason to believe that compliance results from Pennsylvania and Colorado fit within the alleged industry assumptions described by the interviewees.

The violation and compliance data from Colorado and Pennsylvania suggest that operator size has a significant impact on the expected number of violations assessed at a state regulatory inspection. In Colorado, the negative binomial data from the state's compliance dataset indicate that as operators increase in size, they are less likely to commit violations. In CO, the regression

indicated that a shift from small firms to medium sized firms at the margins decreases the average expected number of violations by 0.0982 per inspection holding all else constant. At the margin, larger firms are expected to on average commit 0.1334 fewer violations per inspection than small companies. A similar result was seen in Pennsylvania, where an increase in operator size from a small firm to a medium sized firm led to a decrease in the number of violations per inspection at the margin by 0.0310 holding all else constant, and a decrease in violations at the margin by 0.0542 for large firms compared to small firms. The results from both states were highly significant.

The difference in the magnitude and significance of results between Colorado and Pennsylvania may be explained by the inherent differences between the two states regulatory regime and differences among the operators' active in both states. Colorado has a longer history of drilling and more small operators than Pennsylvania which may relate to a lower number of violations per inspection for large firms. Also, CO's inspection regime, which is much less vigorous than PA's, might have an impact on the number of violations per inspection.

The results from Pennsylvania are consistent with the results from other similar studies conducted in the area. In a 2014 economics paper published by Jonathan Eyer, the author calculated the influence of the number of employees working for an operator in Pennsylvania on that operator's likelihood of committing a violation during an inspection.[81] Eyer uses number of employees as a proxy for operator size, or what he refers to as "legal liability". His results predict that an increase in legal liability corresponds with a 10% decrease in the number of

[81] Eyer J. Does Size Matter? The Effect of Firm Size on Fracking Safety. 2014.

violations per inspection in PA. These results were significant at the 0.05 confidence level.[82] These results are fairly consistent with what was found in this study, albeit a lower effect level.

While somewhat comparable, there are substantial differences between Eyers study and the research conducted here. For example, in this study, operators were lumped into three categorical size bins to measure size instead of using a continuous variable (number of employees) to represent size. For this reason, interpretations from both papers cannot be directly compared; however, trends can still be interpreted.

The results of this study seem to confirm the industry assumptions stated by the study groups. However, it should not be assumed that all large operators are less risky than their smaller counterparts. These results apply to the average grouping of size at the industry level and should be interpreted as general industry wide trends, not expectations at the individual firm level.

The informational interviews with stakeholders provide context and potential leads for explanations for the empirical results calculated in this study. Multiple stakeholders suggested that this assumption might be in place due to fundamental differences in operational capacity between companies of varying size. Larger firms are believed to have better technologies as well as more operational expertise than many small operators. While most small operations are owned and operated by individuals who at one point in their career had been employed by large firms, smaller operations generally do not have the depth of experience that industry giants possess.[83] Larger firms are also generally believed to inherently have a greater capacity to comply with regulations because they can afford to hire and manage entire compliance

[82] Eyer J. Does Size Matter? The Effect of Firm Size on Fracking Safety. 2014.
[83] SMALL 2,3 ENV 1,2 Large 2,4

departments while smaller firms may have one of two people dedicated to ensuring company compliance.

As the natural gas industry begins to understand that poor environmental operating practices may undermine public trust, many large companies have made strong efforts to limit environmental and compliance risk by implementing Environmental Management Systems (EMS).[84] An EMS is a "framework of policy and procedures used to ensure that an organization can fulfill all tasks required to achieve its objectives".[85] In the environmental and compliance context, an EMS is a tool that provides a systematic approach for managing those components of an operation, function, or business that are both critical to achieve a desired level of environmental performance and to enhance regulatory compliance.[86] Many larger firms in the oil and gas industry have begun to adopt this type of "plan-do-check-act" approach to managing environmental risks.[87] The compliance departments of large companies generally operate and manage the EMS programs. These departments set strict goals to prevent and limit environmental compliance issues. Smaller firms often do not have the resources to create an effective EMS or effectively implement it into practice. For this reason, it is possible that smaller companies cannot operate to the same level of compliance as larger firms, not for want or lack of effort, but strictly because of resource limitations.

Along this same line of logic, larger firms may be better able to comply with state regulations due to their operational redundancy. In this context, operational redundancy is the knowledge acquired from repeating the same procedure over and over again in the same or

[84] International Organization for Standardization, ISO 14001:2004, *Environmental Management Systems – Requirements with Guidance for Use,* 2004.
[85] *Id.*
[86] "Prudent Development – Realizing the Potential of North America's Abundant Natural Gas and Oil Resources" National Petroleum Council, 2011. p.230. http://npc.org/
[87] *Id.*

similar conditions. Large operators with many more wells in a state are more likely to have operational redundancy than smaller firms because they will have had more expertise in a state due to the sheer number of wells drilled in the area. For example, a large company with 1,000 wells drilled in PA will most likely be more comfortable with state regulations and know the local geology better than a company that has only drilled four wells in the state. With increased knowledge and comfort in a particular state, one would expect a company to be less likely to commit violations.

Larger firms may also be more compliant with state regulations than smaller firms due to concerns about their public image. With the high level of scrutiny currently focused on the oil and gas industry in the United States, large operators with interests in a number of states and speculative plays, desperately want to preserve a positive public image.[88] If an operator has compliance issues in one state, those problems may not only impact the operators operations in the state in which the violations were committed, but may also impact operations in neighboring states or ultimately a large firms international stock price.

If public trust in a company or the industry as a whole deteriorates due to repeated issues associated with environmental and administrative compliance, the result could be that future or current oil and gas plays become or remain off limits for development.[89] Due to the sheer scale of their operations, larger companies have more to lose by being dirty corporate actors. This

[88] Large 1, REG 1
[89] "Prudent Development – Realizing the Potential of North America's Abundant Natural Gas and Oil Resources" National Petroleum Council, 2011. p.173. http://npc.org/

future financial and exploratory risk incentive may push larger companies to be more compliant than smaller firms.[90]

The interviews with stakeholders also presented information indicating that the accuracy and dependability of state reporting programs may be in question. Respondents resounding told the interviewer that regulatory programs and inspectors are unlikely to be able to regulate all operational parties equally. Most individuals indicated that no matter how well intentioned a regulatory regime is, there will inherently be some bias within the program. This bias was generally thought of to be towards larger operators, creating scenarios in which there is underreporting of large operator violations. Without independent data collection, it is impossible to say with certainty whether or not this true, however, if underreporting of large operators is rampant it would call into questions the validity of the results of this study.

Along with this question of regulatory bias is the question of database accuracy. Even if the regulatory program and its inspectors are unbiased, database management may create problems for anyone attempting to analyze compliance and violation data in Colorado and Pennsylvania. Interviewees indicated that database completeness is an area of concern. Multiple individuals suggested that there is good reason to suspect that state databases may be incomplete due to resource limitations in state compliance offices.[91] While the data may have been collected, it may be the case that it was never uploaded to the reporting database. This was not thought to be the result of maliciousness, but rather a result of underfunded and understaffed

[90] LARGE 1,2: McCreery, J. Phillip, E. Cigala, F. 2013. Operational Excellence: The imperative for oil and gas companies. Bain & Company, Inc. http://www.bain.com/Images/BAIN_BRIEF_Operational_excellence_The%20imperative_for_oil_and_gas_companies.pdf

[91] REG 1, 2, ENV 2,3,4, LARGE 2,3, SMALL 2

state regulatory programs that are often the first agencies to lose funding during budget shortages.

While there is concern about the accuracy of the available oil and gas databases, the majority of those interviewed still believed that valuable information could be gleaned from an analysis of their contents. From these responses there appears to be a trend in thinking that databases are incomplete and potentially biased, however there appears to be no consensus on which way the supposed bias leans. If it is the case that databases are incomplete, then this is another reason to look at any analysis of state oil and gas compliance data from publicly available sites skeptically. However, while there may be questions surrounding the comprehensiveness and bias of state oil and gas reporting databases, the current state databases are the strongest currently available data on this subject.

Section V

Conclusions:

While environmental and administrative compliance in the oil and gas industry appears to be improving, there are still significant areas worthy of improvement. The results of this analysis suggest that larger companies are more adept to comply with state environmental and administrative rules and regulations than smaller companies. This result has strong implications for both regulators and the industry as a whole. From a policy perspective, this may have broad implications for the oil and gas industry and the states that regulate them. If states wish to claim that public and environmental health are their top priorities[92], then there is a strong argument to

[92] COGCC mission statement. http://cogcc.state.co.us

be made that state regulations should be crafted with different operator risks in mind. Due to the increase in violation risk associated with smaller companies, it may be reasonable to increase regulatory oversight or barriers to entry for smaller firms in order to minimize potential environmental harm and mitigate risk.

While some regulations currently in place may act as barriers to entry, only a few interview respondents indicated that they have much if any effect. These current barriers include, bonding requirements, high severance tax rates, and local impact fees. Each of these current barriers were intended to boost state and local revenue and mitigate environmental damages as well as protect against catastrophic risk.

Increasing bonding requirements would force smaller companies to hold larger sums of cash to protect against environmental cleanup costs. In PA for example, the bonding requirement per well starts at $2,500 per well and may increase up to $10,000 based on well bore length.[93] However, an operator's aggregate bonding requirement may not exceed $600,000.[94] When the operating equipment to drill the well in the first place will cost a couple hundred thousand dollars, a bonding requirement of $2,500 is a de minimis expense for producers and may not be sufficient to cover environmental cleanup costs. By increasing bonding requirements, it may have the result of keeping some small operators with limited cash flow out of the state. By making it more difficult for small operators to access a play, states may be able to limit environmental impacts and increase compliance.

The same general principle applies to severance taxes and impact fees. Increases in both of these areas would have a double dividend for states. It would increase revenues for the state

[93] PA Act 13 (2012) http://www.portal.state.pa.us/portal/server.pt/community/act_13/20789/act_13_faq/1127392
[94] PA Act 13 (2012) http://www.portal.state.pa.us/portal/server.pt/community/act_13/20789/act_13_faq/1127392

(severance tax) and local governments (impact fees), while decreasing compliance violations by keeping small companies with small profit margins out of local shale gas plays. Increasing severance taxes would in effect provide more revenue to the state for each unit of oil or gas extracted from the ground. Depending on the price of gas, high severance taxes may cut into the profits of extraction companies and would make it more difficult for firms to operate in the state knowing that their margins will be smaller. Impact fees are generally local fees assessed by municipalities towards oil and gas operators with the intended effect of attempting to recoup losses from damages inflicted to the landscape due to the presence of oil and gas operations. For example, fracking requires a significant amount of heavy machinery and fluids that need to be transported to and from the well site by large trucks. These trucks often damage or destroy rural roads and stress community infrastructure. The money collected from impact fees go towards mitigating these externalities. Higher impact fees will have a similar effect as higher severance taxes; cutting into profits and making it more difficult for smaller operators to work in the state.

Outside of financial requirements, states could also deal with this issue by using command and control regulatory practices. By mandating Best Available Control Technology (BACT) at every well site instead of performance standards from the American Petroleum Institute (API)[95], states can control the type of technology used at the well site. This may be advantageous in some states considering the sheer number of wells being drilled coupled with a state's lack of resources to perform adequate inspections and enforcement. While BACT limits innovation, it will ensure that all companies are using the same equipment and are engaging in the same technical processes that have been approved by the state. BACT may limit the effect of

[95] Currently in use in most states

operator size on compliance as questions over small company equipment and technology would be answered.

Finally, states may look to deal with the problem of operator size influencing compliance by promoting incentive based regulations. While most regulations in the oil and gas industry are focused on the stick, it may be beneficial for states to begin to lead operators towards compliance with a carrot. By instituting clean corporate citizen or green actor provisions, states may be able to incentivize compliance among operators. Clean Corporate Citizen provisions are provisions in which companies that have not committed a violation within a certain time window can be provided benefits from the regulating body. For example, if a company in the unconventional oil and gas industry has not committed a violation in X number of months, then the company may be rewarded with an expedited permitting process which could cut down on permit approval times by months.[96] These types of incentives would be extremely valuable to both small and large producers, as every day that an operator is waiting on a permit is a day in which that operator is not pulling oil and gas from the ground.

While there are strong regulatory implications to this study, there are also far reaching industry implications as well. Considering the high profile and public nature of the oil and gas industry and the difficulty of the general public to distinguish an individual operator from the industry as a whole, the larger oil and gas industry may be interested in industry wide compliance more so than individual operator compliance. If one operator, large or small, has an environmental incident that catches the public's attention, the public may be more likely to have a negative view of the whole industry rather than a negative view of the individual company at

[96] SMALL 1

fault.[97] If this is the case, then the actions of a few small bad operators (whom appear to commit violations more frequently than larger companies) may be harming the larger industry. If public perception of the industry swings negative, then it is possible that the entire industry will suffer as a result of more stringent regulations in place in reaction to public outcry.

To mitigate this threat, large operators with a proven track record of compliance and lots to lose as a result of a few bad actors, may be incentivized to help smaller firms comply with state regulations. Since large firms with redundant expertise have so much to lose as a result of more stringent regulations, or the closing of an oil or gas play, it may be in the best interest of large operators to share information with smaller operators in order to aid them in their compliance efforts. While aiding a competitor may at first seem unwise, the long-run public perception of the industry and those involved in it should trump those concerns. By helping smaller operators comply with environmental and administrative regulations at the well site, large operators may boost public perception of the industry allowing for greater industry wide exploration and production.

This analysis has shown that there appears to be an assumption in the oil and gas industry that smaller operators are riskier than larger ones and that this assumption is backed by compliance and violation data from Pennsylvania and Colorado. While the effect of size on compliance is significant, we cannot say with absolute certainty that size contributes to operator violations. However, from the data collected, there is compelling evidence to recommend that state regulators consider the issue of operator size when crafting new or revising old unconventional oil and gas regulations.

[97] LARGE 1

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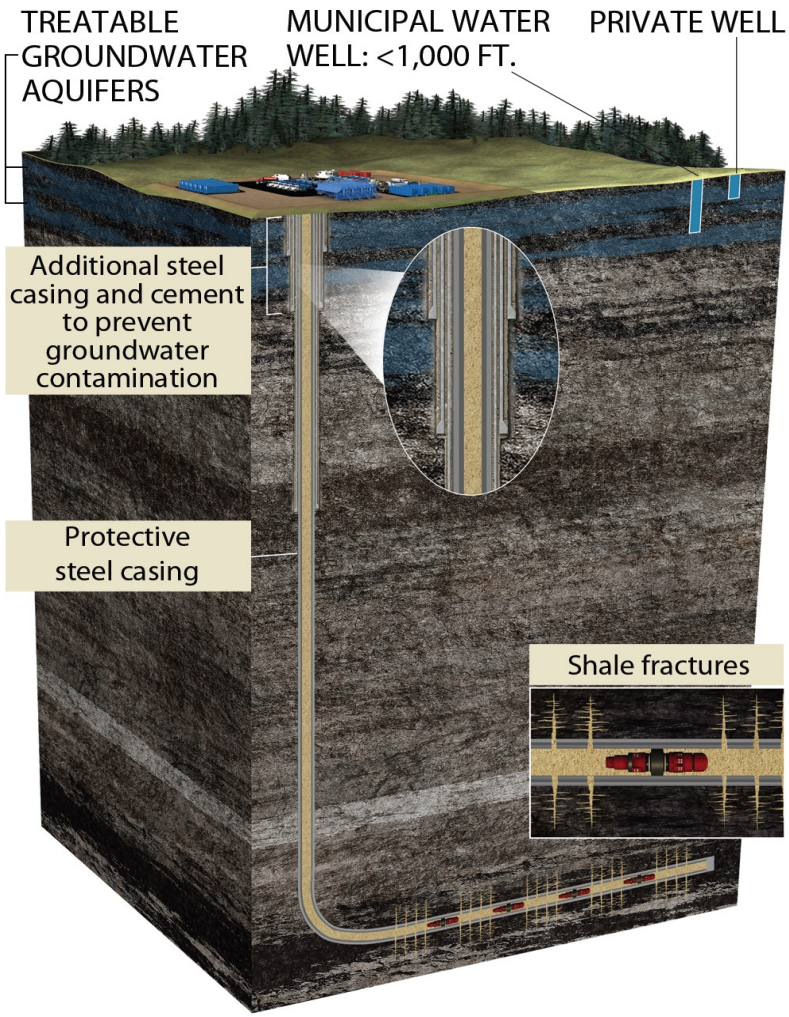
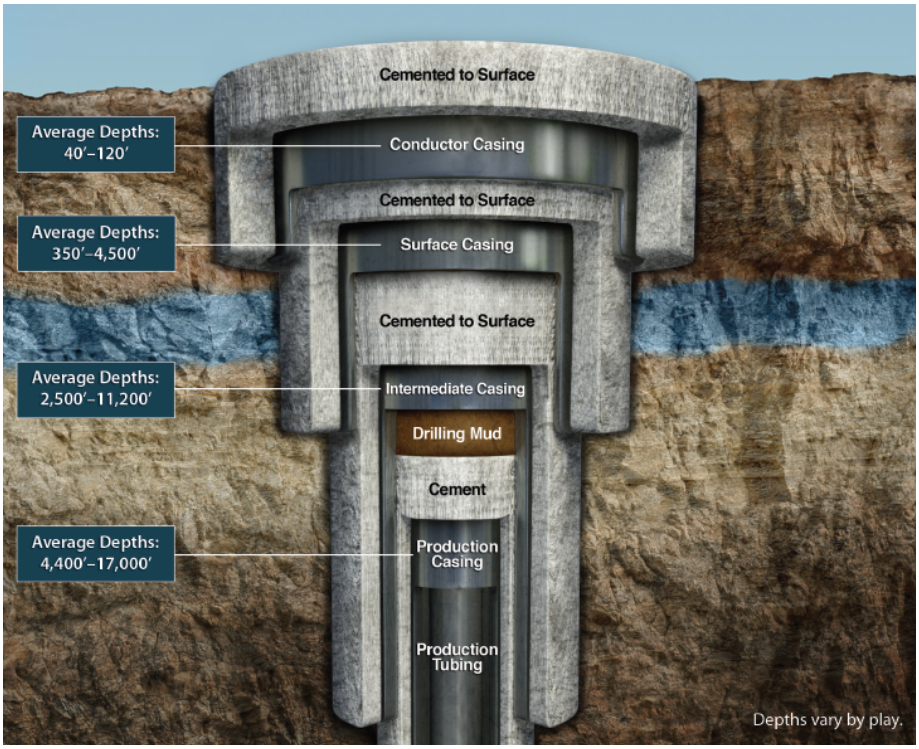
- Timothy Considine, Robert Watson, Nicholas Considine, and John Martin. Environ- mental impacts during marcellus shale gas drilling: Causes, impacts, and remedies. Technical report, State University of New York at Buffalo Shale Resources and Society Institute, 2012.

Appendix:

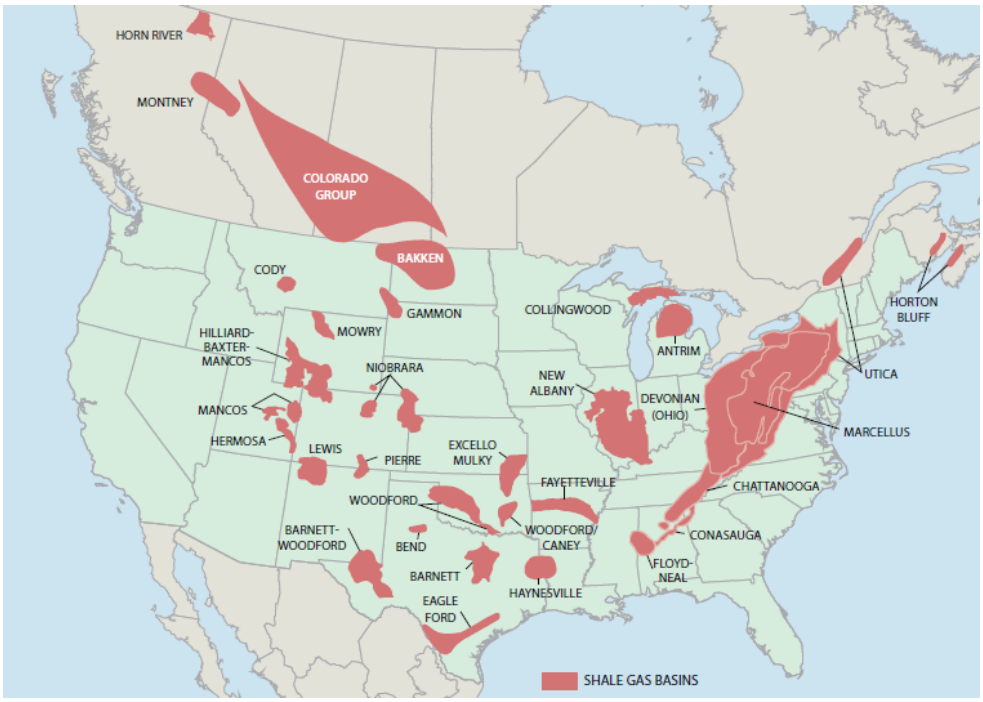


Source: Chesapeake Energy, "Well Stimulation Technology"

Appendix 1. Example of unconventional onshore oil and gas development. Source: Chesapeake Energy, "Well Stimulation Technology" National Petroleum Council, "Prudent Developments"

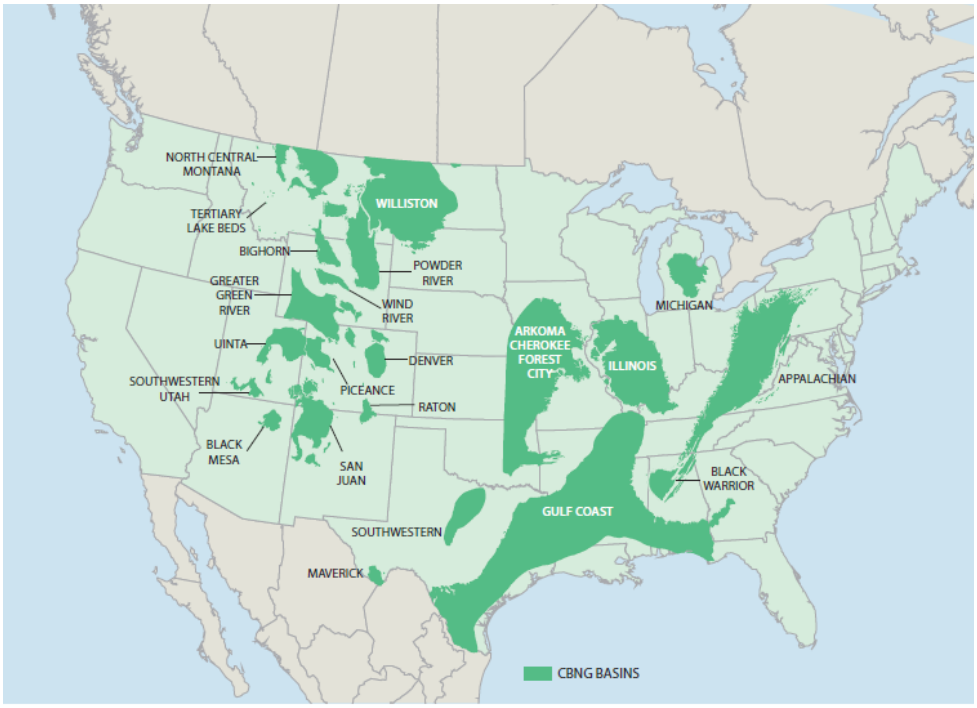


Appendix 2. Wellbore schematic. Source: "Prudent Development – Realizing the Potential of North America's Abundant Natural Gas and Oil Resources" National Petroleum Council, 2011. p.169. http://npc.org/

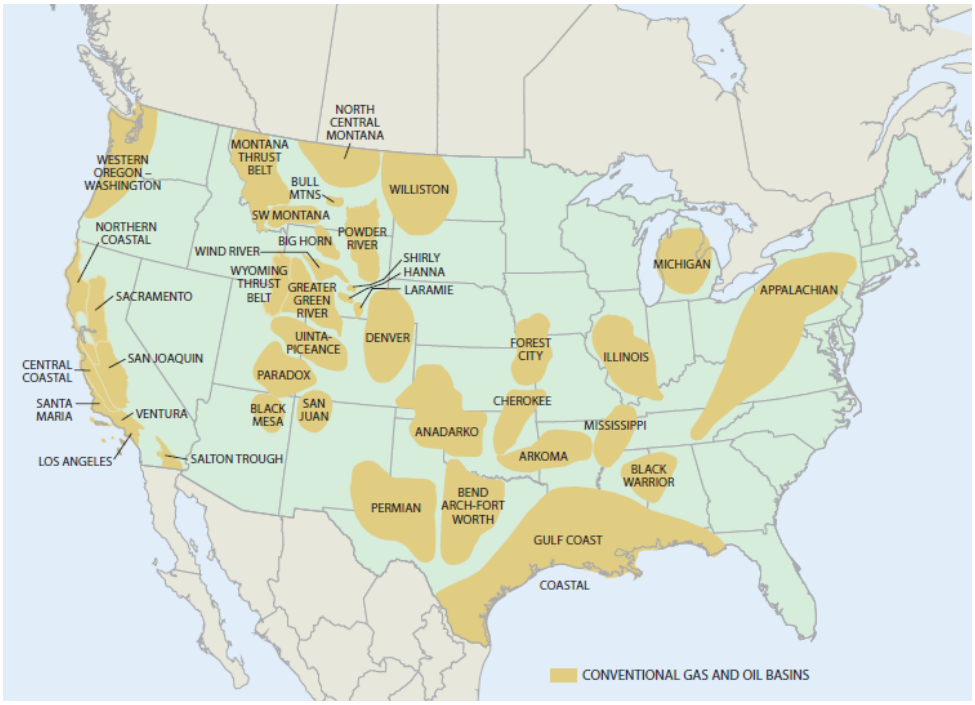


Appendix 3. NA Shale Gas Basins. Source: EIA, 2009

Appendix 4. NA Tight Gas Basins. Source: EIA, 2009



Appendix 5. NA Coal Bed Natural Gas Basins. Source: EIA, 2009



Appendix 6. NA Conventional Oil and Gas Basins. Source: EIA, 2009

Appendix 7. PA Operator size designation chart

Operator	Number of States	Year Incorporated	Number of Wells	International	Public / Private	Market Cap	Inspections	Sum	Size
ALPHA SHALE RES LP	2.5	0.5	3	0	2	4	1	13	**Large**
ANADARKO E&P ONSHORE LLC	4	1.5	3	2	2	4	1.5	18	**Large**
ANTERO RESOURCES CORP	2.5	1	2	0	2	4	1	12.5	**Large**
ATLAS RESOURCES INC	4	1.5	3	0	2	2.5	1.5	14.5	**Large**
CABOT OIL & GAS CORP	2.5	1.5	3	0	2	4	1.5	14.5	**Large**
CARRIZO (MARCELLUS) LLC	4	1.5	3	0	2	2.5	1	14	**Large**
CHESAPEAKE APPALACHIA LLC	4	1.5	3	0	2	4	1.5	16	**Large**
CHEVRON APPALACHIA LLC	4	1.5	3	2	2	4	1.5	18	**Large**
CNX GAS CO LLC	2.5	1.5	3	0	2	4	1.5	14.5	**Large**
CONSOL GAS CO	2.5	1.5	3	0	2	4	1	14	**Large**
DOMINION TRANS INC	4	1.5	1	0	2	4	0.5	13	**Large**
EAST RESOURCES INC	2.5	1.5	3	0	0	2.5	1	11.5	**Large**
ENCANA OIL & GAS USA INC	2.5	1	1	2	2	4	0.5	13	**Large**
ENERGY CORP OF AMER	2.5	1.5	3	2	2	1	1	13	**Large**

ENERPLUS RES (USA) CORP	2.5	1.5	2	2	2	2.5	1	13.5	**Large**
EOG RESOURCES INC	4	1	3	2	2	4	1.5	17.5	**Large**
EQT PRODUCTION CO	4	1.5	3	0	2	4	1.5	16	**Large**
EXCO RESOURCES PA INC	2.5	1.5	3	0	2	2.5	1.5	13	**Large**
HESS CORP	4	1.5	2	2	2	4	1	16.5	**Large**
HUNT MARCELLUS OPERATING CO LLC	4	1.5	2	2	0	1	1	11.5	**Large**
LINN OPR INC	4	1	1	0	2	4	0.5	12.5	**Large**
MARATHON OIL CO	4	1.5	1	2	2	4	0.5	15	**Large**
NOBLE ENERGY INC	2.5	1.5	3	2	2	4	1	16	**Large**
RANGE RESOURCES APPALACHIA LLC	2.5	1.5	3	0	2	4	1.5	14.5	**Large**
RICE DRILLING B LLC	2.5	1.5	3	0	2	4	1	14	**Large**
SAMSON RES CO	4	1.5	2	0	0	2.5	1	11	**Large**
SM ENERGY CO	4	1.5	1	0	2	4	1	13.5	**Large**
SOUTHWESTERN ENERGY PROD CO	4	1.5	3	2	2	4	1.5	18	**Large**
STONE ENERGY CORP	2.5	1.5	2	0	2	2.5	1	11.5	**Large**
SWEPI LP	4	1.5	3	2	2	4	1.5	18	**Large**
TALISMAN ENERGY USA INC	2.5	1	3	2	2	4	1.5	16	**Large**
ULTRA RESOURCES INC	2.5	1.5	3	0	2	4	1	14	**Large**
VICTORY ENERGY CORP	2.5	1.5	1	0	2	4	0.5	11.5	**Large**
WPX ENERGY APPALACHIA LLC	2.5	1.5	3	0	2	4	1.5	14.5	**Large**
XTO ENERGY INC	4	1.5	3	2	2	4	1.5	18	**Large**
ALLIANCE PETROLEUM CORP	2.5	1.5	1	0	0	1	1	7	**Medium**
ALTA OPR CO LLC	2.5	1	2	0	0	1	1	7.5	**Medium**
ANSCHUTZ EXPLORATION CORP	4	1.5	1	0	0	1	0.5	8	**Medium**
ARRINGTON OIL & GAS OPERATING LLC	4	1.5	1	0	0	1	0.5	8	**Medium**
ARUBA PETROLEUM INC	2.5	1.5	1	2	0	1	0.5	8.5	**Medium**
BURNETT OIL CO INC	2.5	1.5	2	0	0	1	1	8	**Medium**
CHIEF OIL & GAS LLC	2.5	1	3	0	0	1	1.5	9	**Medium**
CITRUS ENERGY CORP	2.5	1.5	3	0	0	1	1	9	**Medium**
EM ENERGY PA LLC	2.5	0.5	2	2	2	1	1	11	**Medium**
ENDEAVOUR OPERATING CORP	2.5	1	2	2	0	1	1	9.5	**Medium**
ENERVEST OPR LLC	4	1.5	1	0	0	1	0.5	8	**Medium**
ERGON EXPLORATION INC	4	1.5	1	0	0	1	0.5	8	**Medium**
HALCON OPR CO INC	2.5	0.5	2	0	2	1	1	9	**Medium**
HILCORP ENERGY CO	4	1.5	3	0	0	1	1	10.5	**Medium**

INFLECTION ENERGY (PA) LLC	2.5	0.5	3	0	0	1	1	8	**Medium**
J W OPERATING CO	4	1.5	2	0	0	1	1	9.5	**Medium**
NOVUS OPERATING LLC	2.5	0.5	2	0	0	1	1	7	**Medium**
OPEN FLOW GAS SUPPLY CORP	2.5	1.5	1	2	2	1	0.5	10.5	**Medium**
PA GEN ENERGY CO LLC	1	1.5	3	0	0	1	1.5	8	**Medium**
PDC MOUNTAINEER LLC	2.5	1.5	1	0	2	2.5	0.5	10	**Medium**
PENN VIRGINIA OIL & GAS CORP	2.5	1.5	2	0	2	1	1	10	**Medium**
PETRO DEV CORP	2.5	1.5	1	0	2	2.5	0.5	10	**Medium**
RE GAS DEV LLC	2.5	1	3	0	2	1	1	10.5	**Medium**
REX ENERGY OPERATING CORP	2.5	1	3	0	2	1	1	10.5	**Medium**
SENECA RESOURCES CORP	2.5	1	3	0	0	1	1.5	9	**Medium**
SNYDER BROS INC	1	1	3	0	0	1	1	7	**Medium**
TENASKA RES LLC	2.5	1.5	3	0	0	1	1	9	**Medium**
TEXAS KEYSTONE INC	2.5	1.5	2	0	0	1	0.5	7.5	**Medium**
TRIANA ENERGY LLC	2.5	0.5	3	0	0	1	1	8	**Medium**
US ENERGY EXPLORATION CORP	4	1.5	1	0	2	1	0.5	10	**Medium**
VANTAGE ENERGY APPALACHIA II LLC	2.5	0.5	3	0	0	1	1	8	**Medium**
VISTA OPR INC	2.5	1.5	1	0	0	1	1	7	**Medium**
AB RESOURCES PA LLC	2.5	0.5	2	0	0	1	0.5	6.5	**Small**
AMER OIL & GAS LLC	1	0.5	1	0	0	1	0.5	4	**Small**
APEX ENERGY (PA) LLC	1	0.5	1	0	0	1	0.5	4	**Small**
ARMSTRONG GAS CO LLC	2.5	1	1	0	0	1	0.5	6	**Small**
BAKER GAS INC	1	0.5	1	0	0	1	0.5	4	**Small**
BELDEN & BLAKE CORP	2.5	1.5	1	0	0	1	0.5	6.5	**Small**
BLX INC	1	1.5	2	0	0	1	1	6.5	**Small**
BURKLAND WILLIAM S	1	1.5	1	0	0	1	0.5	5	**Small**
CAMPBELL OIL & GAS INC	1	1	1	0	0	1	1	5	**Small**
DANNIC ENERGY CORP	1	1.5	1	0	0	1	0.5	5	**Small**
DE LTD FAMILY PARTNERSHIP	1	1	1	0	0	1	0.5	4.5	**Small**
DL RESOURCES INC	1	0.5	1	0	0	1	0.5	4	**Small**
DORSO LP	1	1.5	1	0	0	1	0.5	5	**Small**
FLATIRONS DEVELOPMENT LLC	2.5	0.5	1	0	0	1	1	6	**Small**
GREAT OAK ENERGY INC	1	1.5	1	0	0	1	0.5	5	**Small**
GREAT PLAINS OPER LLC DBA GREAT MTN OPER	2.5	0.5	1	0	0	1	0.5	5.5	**Small**

GUARDIAN EXPLORATION LLC	2.5	1	1	0	0	1	1	6.5	**Small**
JR RESOURCES LP	1	1.5	1	0	0	1	0.5	5	**Small**
LONGFELLOW ENERGY LP	2.5	0.5	1	0	0	1	0.5	5.5	**Small**
M & M ROYALTY LTD	2.5	1	1	0	0	1	0.5	6	**Small**
MDS ENERGY DEV LLC	1	0.5	3	0	0	1	1	6.5	**Small**
MID EAST OIL CO	1	1.5	1	0	0	1	0.5	5	**Small**
MIEKA LLC	2.5	0.5	1	0	0	1	1	6	**Small**
MTN V OIL & GAS INC	2.5	1	1	0	0	1	0.5	6	**Small**
NORTHEAST NATURAL ENERGY LLC	2.5	0.5	2	0	0	1	0.5	6.5	**Small**
PATRIOT EXPLORATION CORP	1	0.5	1	0	0	1	0.5	4	**Small**
PENNENERGY RESOURCES LLC	1	0.5	3	0	0	1	1	6.5	**Small**
PHILLIPS EXPLORATION INC	1	0.5	3	0	0	1	1	6.5	**Small**
POWER GAS MKT & TRANS INC	1	1	1	0	0	1	0.5	4.5	**Small**
REDMILL DRILLING	1	1.5	1	0	0	1	0.5	5	**Small**
SOMERSET REG WATER RESOURCES LLC	1	0.5	1	0	0	1	0.5	4	**Small**
T & F EXPLORATION LP	1	1	1	0	0	1	0.5	4.5	**Small**
TANGLEWOOD EXPL LLC	2.5	0.5	2	0	0	1	0.5	6.5	**Small**
TRUE OIL LLC	2.5	1.5	1	0	0	1	0.5	6.5	**Small**
TURM OIL INC	1	1.5	2	0	0	1	1	6.5	**Small**
WILLIAM MCINTIRE COAL OIL & GAS	1	0.5	2	0	0	1	0.5	5	**Small**

Appendix 8.

McHenry Master's Project Interview Questions

Interviewee:_____

Date:_____

- What is your relation to the oil and gas industry?
- Would you consider yourself to be a regulator, policy advocate, representative of a large producer, or a representative of a small producer?
- Could you briefly describe the parties involved in the drilling of an unconventional oil and gas well and their relationship?
- Are there different classes of companies engaged in shale gas development around the country? If so, what are they and how would you classify them? Are there differences among classes of well owners/operators?
- How would you define large and small companies in the hydraulic fracturing industry?
- Would you say that there are any generalized assumptions in the industry regarding differences between large and small operators?
- Do large and small companies use the same types of drilling and safety equipment at the well site during exploration? Production?
- Do small and new companies have the same level of technical expertise and experience as larger companies? Does this have any influence on compliance with state regulations?
- Does the industry perceive there to be any differences in regulatory compliance between small and large companies? Administrative v. Environmental?
- Have some state regulations, in those states engaged in the hydraulic fracturing industry, been crafted in a way that would promote the business of one type of company over another? If so, what types of regulations?
- Have some states created barriers to entry for small companies?
- Should there be different environmental and administrative regulations for hydraulic fracturing companies of different sizes and experience?
- Are state regulatory agencies capable of regulating large and small processors equally?
- Do state regulators interact with small and large companies the same way?
- How accurate are state violation reporting programs and are these programs evenly enforced?
- Are there any general trends in the industry with regards to compliance and enforcement?
- How do you see the unconventional oil and gas industry changing in the next five years?